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Risk and Safety in Post-Soviet Russia

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14. ABSTRACT
This document presents the results of a study of risk and safety for the population of Russia. It was prepared shortly after the dissolution of the USSR, when Russia was dealing with several zones of ecological distress as a consequence of a number of large-scale technogenic disasters, including some serious radiation situations. All these events had a pronounced negative effect on the general living conditions and led to a reduction of life expectancy, a sharp increase of morbidity and mortality, and harmful genetic aftereffects for the populations involved. National health and life expectancy have improved considerably since then; however, the author's analysis of the situation is still helpful for modern risk and safety considerations. Part I is a detailed analysis of the risk of death for the population of the Russian Federation due to disease, exposure to natural and man-made environments, professional and non-professional activity, and various social factors. Part II studies radiation exposure databases from Chernobyl, radioactive contamination from long-term operation of large radiochemical atomic plants, and the impact of atmospheric nuclear tests. The author proposes a new approach to radiation risk assessment, which is based on consideration of the distribution of both radiation doses and individual variations in radiosensitivity.

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Radiation risk assessment; Radiation contamination; Risk analysis
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CONVERSION TABLE

Conversion factors for U.S. Customary to metric (SI units of measurement)

MULTIPLY TO GET	BY BY	TO GET DIVIDE
angstrom	1.000 000 x E-10	meters (m)
atmosphere	1.012 25 x E +2	kilo pascal (kPa)
bar	1.000 000 x E + 2	kilo pascal (kPa)
barn	1.000 x E – 28	meter^2 (m^2)
British thermal unit (thermochemical)	1.054 350 x E + 3	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical)/cm^2	4.184 000 x E-2	mega joule/m^2 (MJ/m^2)
curie	3.700 000 x E + 1	giga becquerel (GBq)*
degree (angle)	1.745 329 x E – 2	radian (rad)
degree (Fahrenheit)	Tk = (t +459.69)/1.8	degree kelvin (K)
electron volt	1.602 19 x E – 19	joule (J)
erg	1.000 000 x E – 7	joule (J)
erg/sec	1.000 000 x E – 7	watt (W)
foot	3.048 000 x X-1	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (U.S. liquid)	3.785 412 x E – 3	meter^3 (m^3)
inch	2.540 000 x E -2	meter (m)
jerk	1.000 000 x E + 9	joule (J)
joule/kilogram (J/kg) (absorbed dose)	1.000 000	Gray (Gy)**
kilotons	4.183	terajoules
kip (1000 lbf)	4.448 222 x E + 3	newton (N)
kip/inch^2 (ksi)	6.894 757 x E +3	kilo pascal (kPa)
ktap	1.000 000 x E +2	newton-second/m^2 (N-s/m^2)
micron	1.000 000 x E – 6	meter (m)
mil	2.540 000 x E – 5	meter (m)
mile (international)	1.609 344 x E + 3	meter (m)
ounce	2.834 952 x E – 2	kilogram (kg)
pound-force (lbf avoirdupois)	4.448 222	newton (N)
pound-force inch	1.129 848 x E – 1	newton-meter (N*m)
pound-force/inch	1.751 268 x E + 2	newton-meter (N/m)
pound-force/foot^2	4.788 026 x E – 2	kilo pascal (kPa)
pound-force/inch^2 (psi)	6.894 757	kilo pascal (kPa)
pound-mass-foot^2 (moment of inertia)	4.214 011 x E – 2	kilogram-meter^2 (kg*m^2)
pound-mass/foot^3	1.601 846 x E + 1	kilogram/m^3 (kg/m^3)
rad (radiation absorbed dose)	1.000 000 x E – 2	Gray (Gy) **
rem (roentgen equivalent man)		Sievert (Sv) ***
roentgen	2.579 760 x E – 4	coulomb/kilogram (C/kg)
shake	1.000 000 x E – 8	second (s)
Slug	1.459 390 x E + 1	kilogram (kg)
Torr (mm Hg, 0 degrees C)	1.333 22 x E – 1	kilo pascal (kPa)

* *The Becquerel (Bq) is the SI unit of radioactivity: 1 Bq = 1 event/s.*

** *The Gray (Gy) is the SI unit of absorbed radiation.*

*** *The Sievert (Sv) is the SI unit of dose equivalent.*

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ABSTRACT

This document presents the results of a study of risk and safety for the population of contemporary Russia. The Russian Federation inherited from the USSR several zones of ecological distress and calamity as a consequence of a number of large-scale technogenic disasters. These included some serious radiation disasters responsible for the widespread radioactive contamination of the environment. All these events had a pronounced negative effect on the general living conditions and led to a reduction of life expectancy, a sharp increase of morbidity and mortality, and harmful genetic aftereffects for the population involved. The risk and safety analysis was based on our own views of the general safety theory briefly formulated in the Introduction.

Part I is a detailed analysis of the risk of death for the population of the Russian Federation due to disease, exposure to natural and man-made environments, professional and non-professional activity, and various social factors. The proposed approach to risk analysis considers the age dependence of the risk of death from disease to be a fundamental characteristic of a population. All external effects on the organism are perceived as a kind of perturbations that manifest themselves at different sections of this dependence. Based on this, an attempt is made to analyze separately the contributions of all competing sources of the risk of death and to determine their effects on life duration in Russia.

Part II concentrates on estimations of radiation risk for the Russian population in view of the considerable radioactive contamination of some of Russia's territories. The procedure of assessment of risk in all the situations described in the text includes two stages. We first determined the distribution of radiation doses among the affected residents. Then we passed from radiation doses to the evaluation of risk of adverse effects. We propose a new approach to radiation risk assessment, which is based on consideration of the distribution of both radiation doses and individual radiosensitivity among the public (Section 13.0).

Editor's Note: The data for this document were collected in 1996 and 1997, over a decade ago. The quality of life in the Russian Federation has improved. It is possible that some of the conclusions of the author would also have changed to correspond with newer data indicating an overall improvement in national health and life expectancy.

It should also be stressed that this document, including the collection of data, its presentation, and the conclusions derived are entirely the work of the author. The Defense Threat Reduction Agency (DTRA) and its predecessor agencies did not collaborate in the analysis of data or in the preparation of the report, aside from correction of grammatical structure and syntax plus updating radiation units to SI units. Editorial changes were carefully made in order not to alter the scientific content of the document, only its format and presentability. Consequently, the findings and opinions expressed in this document are entirely those of the authors and do not represent those of DTRA, the Department of Defense, or the U.S. Government. Funding and contractual management support for the production and publication of this report were provided by DTRA. Scientific review and editing for clarity was performed by Dr. Glen I. Reeves, MD, of Northrop Grumman IT. The agency is grateful for the report production and technical editing provided by Chris Brahmstedt of the Defense Threat Reduction Information Analysis Center (DTRIAC) for this report.

Addendum: The author, Professor Eugene E. Kovalev, received his Ph.D. and Doctor of Science from the Institute of Biophysics in Moscow. He was named an Honored Scientist of the Russian Federation in 1976 and received a USSR State Prize in 1978. He was the head of the National Space Radiation Protection Service from 1975 to 1990. In 1990 the Research Center of Spacecraft Radiation Safety (RCSRS) was established, and Prof. Kovalev was named its first Director serving till his retirement in 1997.

The chief tasks of the RCSRS were:

- Radiation protection of spacecraft crews in long-term space flight, including protection from nuclear propulsion equipment and onboard nuclear power plants
- Radiation protection in military missions in space
- Estimation of radiation risk in space flight

The RCSRS is now called the Federal State Unitary Enterprise Research and Technical Center of Radiation-Chemical Safety and Hygiene. It is located in Moscow.

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PART I. ANALYSIS OF RISK OF DEATH FOR THE POPULATION OF RUSSIA

1.0: RELATIONSHIP BETWEEN SAFETY AND RISK

1.1 INTRODUCTION

The concepts of "hazard" and "safety" are now widely used in many different areas of human activity since nearly all activities are associated with a certain risk of some deleterious effects. These effects can include disease, injury, or even death. In this connection, there arise some questions of practical importance. When is this hazard unacceptable? Where does the boundary between hazard and safety lie? Can safety be regarded as a complete absence of any hazard? To answer these questions one needs to have a universal measure of hazard and safety. We believe that "risk" can serve as such a universal quantitative measure. In this section we make attempts to elucidate the relationship between "hazard" and "safety" on the basis of the acceptable risk concept mostly using our earlier publications (1-8).

1.2 MAIN TERMS AND DEFINITIONS

Here we introduce a few terms which will be used in the subsequent text of this document. "**Hazard**" is a situation that can lead to an injury, disease, or other early or delayed adverse effects which restrict a person's activity and result in a reduction of expected lifetime or death. A quantitative measure of hazard is taken to be "**risk**". Risk is the probability of any adverse effect that restricts a person's activity, reduces his expected lifetime and/or leads to death. There is an alternative definition of the term "**risk**": the probability of an event leading to a detriment multiplied by the magnitude of this detriment. "**Safety**" is a situation when risk does not exceed the established acceptable level. The quantity "**acceptable risk**" can be quantitatively established with any given accuracy. There are also two additional terms to be used here. "**Hazard index**" is the common logarithm of the ratio of the current individual risk to its baseline value. We assume that the annual baseline individual risk is 10^{-10}. The origin of the abscissa (0) corresponds to the baseline risk and the abscissa's maximal value (10) corresponds to death hazard (the risk of death is 1). "**Safety index**" is the ratio of the average life expectancy at birth to a lifetime of 100 years.

An adequate notion of hazardous/nonhazardous or nonsafe/safe conditions could be obtained by means of a plot of safety index versus hazard index. As an illustration, let us assume that, in a region, the current annual individual risk is 10^{-5} and the average life expectancy at birth is 75 years. Then the index of hazard (the abscissa) is 5 and the index of safety (the ordinate) is 0.75. One has to know the dynamics of these indices to be able to adequately characterize the safety conditions in this region. The use of this diagram helps reveal trends which are present in the hazard-safety interaction under any specific conditions.

1.3 PROBLEMS OF ACCEPTABLE RISK

It is well known that any kind of human activity entails some negative consequences which can lead to a disease or even death. Any kind of human activity is responsible for an increase in adverse effects for man and also for the environment. In the ideal case, the acceptable risk should correspond to a balance between risk and benefit from a particular kind of activity. The expenditures required to take adequate measures against a hazard depend on the acceptability of risk of adverse effects (6, 8). The problem of acceptable risk has social, economic, and other aspects. The social aspects of this problem manifest themselves in the way the benefits and harmful effects of a technogenic activity are distributed between different social groups of a society. In other words, the benefits from an enterprise or project may be appropriated by some members of the society, whereas the risk of deleterious effects of this project may be experienced by quite other members or by the society as a whole. The economic aspects of the problem of acceptable risk become evident when considering the cost of reducing risk to a given level or when analyzing losses due to an insufficiently low risk level. By expressing these costs and losses in the same units, which by itself is not an easy task, and then summing them up, one can estimate the economic expediency of protective measures. Evidently, this provides a possibility to find a minimal value of the sum of losses and costs that would correspond to optimal conditions of implementing these measures. The risk corresponding to a minimal sum of losses and costs can tentatively be called acceptable.

The psychological problems of acceptable risk are very complicated and insufficiently studied. Each individual has his (her) own scale of assessing the risk of adverse effects connected to his (her) participation in various sorts of activity. Although it is generally accepted now that absolute safety cannot be achieved, to obtain psychological consent to a risk is not an easy matter. This can be partially due to both an overestimation of the relevant statistical data and to ambiguous terminology used in considering the acceptable risk problem. Certain psychological difficulties also arise with respect to risk involved in absolutely novel occupations. Society accepts, though sometimes with deep concern, the risk associated with occupations it is accustomed to, but often rejects the same, or an even lower, level of risk specific to new areas of human activity (3). Consequently, to justify an acceptable risk in various occupations it is necessary to find the conditions of a minimal sum of costs for a given level of safety and losses owing to insufficient protection against the hazard. This often involves difficulties because the exact form of the dependence of costs and losses on the risk level in most cases is unknown. The conditions of the minimum sum of risks and, accordingly, the levels of acceptable risk can be found by studying the extent of risk underlying the life of a contemporary man. This conclusion is based on admitting the existence in the society of spontaneous tendencies to establish an acceptable cost-benefit balance for each occupation. The society moves toward such a balance in an empirical way, by trial and error, and by successively correcting the errors.

1.4 CLASSIFICATION OF RISK SOURCES

Individual risk in a modern society can stem either from some stochastic events or from a prolonged action of a source of hazard, or both. When studying and comparing various sources of hazard, one should first of all bear in mind the finite probability of death of every man resulting from genetic and somatic diseases and the natural aging of the organism. Therefore, the internal environment of man is a principal source of risk of death. Another source of hazard is the natural environment, which frequently undergoes various perturbations leading to injuries and deaths of many people

(earthquakes, floods, hurricanes, etc.).

The technological evolution of humanity created some specific conditions of life which can be called "the man-made environment." It provided a higher independence of man from the negative impact of many phenomena, thereby facilitating the development of civilization. The man-made environment, however, is responsible for the appearance of a number of new sources of hazard for man and a corresponding increase of individual risk. The main causes of death directly related to the man-made environment include home and transport accidents, diseases induced by contamination with industrial and transport releases, etc.

Many adverse effects are due to human professional activity. These include occupational diseases, work accidents, fires, and large-scale disasters. Also people sometimes engage in various non-occupational kinds of activity, such as amateur sports, which involve additional hazards of injury, disease or death.

Finally, a potential source of risk of death is the social environment. It is largely responsible for such purely social causes of death as crimes, wars, drug addiction, alcoholism, suicides, and so on.

To facilitate a quantitative estimation of the risk of adverse effects, we propose a classification of sources of the risk of death given in Table 1.1 (1, 2, 4, 5, 7, and 8). This classification could serve as a basis for comparison of risks in various areas of human activity in advanced countries.

Note that it is only in the first approximation that the above-mentioned risk sources affect people independently of one another. In actual life, the sources of risk of adverse effects form complicated combinations, which often obscure the true picture, and we have to speak about the so-called principal causes of death (7, 8). A more thorough analysis must take into account the interaction of the internal environment of an organism with other sources of risk. For instance, natural cataclysms have more serious consequences for old and sick persons. The same applies to the effects of accidents.

1.5 RANGES OF RISK OF DEATH IN ECONOMICALLY DEVELOPED COUNTRIES

To compare risks of different causes of death easier and more vividly, it is useful to reduce all levels of risk to one hour of activity or life. The data shown below refer to economically advanced countries (5, 7).

The range of individual annual risk can be very large: from 10^{-1} to 10^{-10}. This corresponds to a hazard index (described in Section 1.2) of 0 to 9. A minimal detectable risk (hazard index below 1) corresponds to isolated small-scale events that occur in the natural environment of man and lead to several deaths annually all over the world. A hazard index below 2 corresponds to a negligible risk. Hazard index 3 is assigned to risks of death related to, e.g., radioactive substances in consumer goods and TV radiation. The risk of death from these exposures to the man-made environment is below, or in any case comparable, to, say, the risk of being killed by a lightning bolt during a storm. A hazard index from 3 to 5 includes all exposures to currently used man-made radiation sources and to natural disasters.

Technogenic accidents or disasters (smog, gas explosions, emergency releases, etc.) and also continuous releases from thermal power plants lead to risk of death corresponding to hazard indices of 5-6. In the same range of hazard indices are occupational risks in traditionally "safe" industries. The upper limit of this range applies to the risk of death from leukemia corresponding to the incidence of this disease among the population. The range of hazard index 6-7 starts with the risk of death from disease in the age group of 10-14 years (the minimal risk of death from disease) and ends with the same risk at 30-34 years. Against the background of gradually increasing mortality in going from younger age groups to middle ones, the risk of death within this range increases due to the influence of man-made environment and occupational factors. This range includes risk of death from all industrial factors (on the average) and from accidents in public transport and railways.

The range of hazard index exceeding 7 starts with the risk of death from disease at the age of 35-39 and ends with the same risk at 50-54. The range also includes an increased mortality from accidents at 20-24 years and the steadily increasing risk of death from both disease and accidents at ages from 45 to 85 and above. The same range of indices applies to the work of fishermen, miners, and railway workers, to safety conditions in motor-vehicle and air transport, and in such sports as bicycling, amateur boxing, hunting, and skiing.

Hazard indices 8-9 correspond to risk of death from disease in the age group of 55-60 years and to the average risk of death from disease for the whole population. The upper limit of this range corresponds to the risk of death from disease at the age of 70-80 and includes various high-risk occupations (such as jet-bomber pilots).

The hazard index range from 9 to 10 begins with the level of risk of death from disease at the age of 80-84. It is followed by the same risk at 85 and older. It also includes particularly dangerous occupations (high-altitude jet-fighter pilots, test pilots, etc.) and sports (high-altitude climbing, mountaineering, etc.). These hazard indices seem to exceed any natural levels of mortality (diseases).

The study and comparison of risks of death for contemporary man in advanced countries suggest some conclusions that may be useful when approaching the acceptability of risk, in particular, in elaborating the criteria of ecological safety of the public. (1) In the hazard index range 0-5, one can use mortality from various natural cataclysms as a yardstick of hazard. (2) The internal environment of the organism is a major source of risk of death (hazard index > 5). The average level of risk of death from disease for males of all ages, as well as for the population as a whole, can only be compared with the risk of death in particularly hazardous occupational conditions, in some dangerous sports, or in non-nuclear war. (3) Among the causes of death of contemporary man in economically prosperous countries, an important role belongs to accidents originating in the man-made environment and various professional and non-professional activities (hazard index 5-9).

1.6 CONCLUSIONS

This chapter considers the relationship between hazard and safety in the framework of the concept of acceptable risk that has been elaborated on an interdisciplinary basis. The problem of assessment of the situation in any area of human activity from the viewpoint of its safety for the public is then reduced to risk analysis, which poses the problem of justification of levels of acceptable risk.

The classification of risk presented here forms the basis of an analysis of risk of death for the population of Russia given in the rest of Part I, where each chapter deals with a particular source of this risk.

Table 1.1. Classification of Sources of Risk of Death.

Source	Main Causes of Death
1. Internal environment	Genetic and somatic diseases
2. Natural environment	Accidents during earthquakes, floods, hurricanes, etc.
3. Man-made environment	Transport and home accidents, diseases due to environmental contamination, etc.
4. Professional activity	Occupational diseases, work accidents
5. Nonprofessional activity	Diseases and accidents in amateur sport and other kinds of nonprofessional occupation
6. Social environment	Suicides, self-inflicted injuries, homicides, war injuries and deaths, etc.

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2.0: INTERNAL ENVIRONMENT OF THE BODY AS A SOURCE OF DEATH RISK

2.1 INTRODUCTION

When examining various risk sources one should primarily bear in mind the inevitable eventual endogenous death of any person owing to some somatic and/or genetic diseases and to the natural aging, i.e., to failures of the body internal environment. The internal environment also determines the organism's response to various adverse factors of different etiology (physical, chemical, biological, social, etc.).

Here and in all subsequent sections, we take the average probability of individual death per unit time as a quantitative measure of individual risk. We shall mainly operate with the data on mortality of various etiologies referred to a period of one year.

According to latest views, of all the existing criteria of public health, mortality seems to be the most reliable and information-rich index (1). Mortality is a traditional indicator of loss of a person's health. Statistically reliable and unbiased mortality indices make possible meaningful inter-region comparisons inside the Russian Federation, as well as comparison with corresponding data for other countries of the world. A drawback of mortality indices is that they contain no information on the general status of health of the population. On the other hand, the top priority for a health care service is to preserve human lives (1), and this is fully consistent with the aim of providing public safety.

In recent years (particularly after 1991), official publications (2, 3), state reports (4-6), and other relevant materials (7, 8) dealing with the problem of public health in the Russian Federation have become available. In 1995, the Environmental and Health Atlas of Russia saw the light of day (1). This atlas is in effect an encyclopedia on the interaction of public health and environmental conditions interaction. Data from the above-mentioned publications have been used in this section. The section considers the reliability of the internal environment of the human organism, the age dependence of the risk of death from a disease, risk of death from various diseases for the Russian population over a fairly long period of time, and also the same risk for separate regions and republics of the Russian Federation. At the end of this section are reference data in tabulated form: Table 2.5, Male-Female Composition by Age Groups of the Russian Population, 1939-1994; Table 2.6, Mortality of the Russian Population in 1960-1993; Table 2.7, Comparison of Population Mortality in Russia and Other Countries in 1990 and 1992; Table 2.8, Age Coefficients of Mortality for the Russian Population; Table 2.9, Mortality of the Russian Population Due to Principal Causes of Death; and Table 2.10, Population Mortality in Various Territories of the Russian Federation.

2.2 RELIABILITY OF THE INTERNAL ENVIRONMENT OF THE HUMAN ORGANISM

Living systems change with time, so they are dynamic systems. The dynamic systems are characterized by two types of feedback: negative and positive. An external effect on the living organism represents a signal arriving at the input of the living system. In the presence of negative feedback, part of the output signal from the exit of the system gets to the system entrance, so that the ratio of the final output signal to the initial input signal is smaller than unity. Thus, a negative feedback diminishes the output signal as the input signal increases, i.e., it is a mechanism of system

self-correction. The mechanisms of self-correction of living systems provide their relative independence of the influence of external environmental conditions. As a result, a living system is insensitive to external perturbations, but only within a certain range of these perturbations.

The state of dynamic equilibrium of a living system is described by the term "homeostasis," which is the maintenance of internal constancy and independence of the external environment. Internal constancy can be achieved if there is negative feedback which holds the system within the region of equilibrium between organism and environment. The term "homeostasis" is frequently used in describing the process of biological self-regulation of the body functions. All living systems undergo changes with time and finally die. Consequently, all living systems are in a state of development, i.e., a state of homeokinesis.

For each system there is a stable state of dynamic equilibrium which it is striving to reach but never can. The self-regulation processes occurring in a living system can be considered as attempts of the system to achieve a state of equilibrium and to preserve it, i.e., to remain within the homeokinetic plateau (HKP). This plateau can be considered a region of nonequilibrium state of the system in which every system strives for self-regulation.

On each side of the HKP there are regions of positive feedback: as the system approaches them, it arrives at the end of its existence and undergoes destruction. For a positive feedback, the ratio of the output signal to the input one is a quantity larger than unity, and this is detrimental for the system. Thus, positive feedback represents the presence of destabilizing conditions.

The biological processes in the human body are directed towards the maintenance of a relative dynamic constancy of the internal environment and the principal physiological functions. This provides the necessary conditions for the homeostasis of the internal environment of the human body. The homeostatic state is gradually improving in the course of the organism's development, and this ensures a high reliability of functioning of all body systems. Homeostasis also provides a high level of the organism's resistance to diseases, of both endogenous and exogenous origin, to various kinds of stress, injuries, and other adverse effects of the external environment.

The adaptivity and reliability of homeostasis decreases on changing from the 10-14 year group to older age groups, and the probability of contracting a disease and of dying increases accordingly. This is accompanied by a gradual reduction of the homeokinetic plateau. Many external influences that in the 10-14 age group are easily compensated for by self-regulatory processes, in older age groups induce some destabilizing conditions, which lead to the region of positive feedback and ultimately to the organism's death.

Thus, the size of the HKP strongly depends on the organism's age. At birth this plateau is very small. It then it grows drastically, reaching its maximum at 10-14 years, and then gradually decreases at older ages.

If one assumes that the size of the HKP is inversely proportional to the average mortality rate in the same age group, one can obtain estimates of the HKP size in arbitrary units (Table 2.1). We assumed the average size of the HKP for 10-14 years to be unity. The estimates were based on the age-specific mortality data for the Russian population in 1989 (8). One can see that the greatest changes of the

average size of the HKP take place in the early years of a child's life. The high rate of failure of the child's internal environment, which imposes special demands on its external environment, quickly decreases and becomes minimal at the age of 10-14 years. At that age the reliability of functioning of a human organism is at its maximum. Later, and very gradually, the regressive processes (aging) start to become noticeable, thereby reducing the reliability of the internal environment. The resistance of the organism to the external factors reduces accordingly, and the need for creating milder living conditions becomes more pronounced.

The size of the HKP, as well as the average mortality rate, depends not only on the age and sex, but also on many other factors, such as geographic, climatic, social and economic conditions, the surrounding medium, and so on. That is why there is a considerable variability of the HKP size within the same age group. If one assumes that the HKP size at a given age has a normal (Gaussian) distribution (like many other biological, physiological, and other indices) and that the coefficient of variation (the ratio of mean square deviation to mathematical expectation) is 1/3 independent of age, one arrives at the following conclusions.

> (1) Whereas in the group with maximum reliability of the organism's internal environment (10-14 years) the mean relative size of the HKP is 0.1, about 34% of the group's members have a relative HKP size below 1.0 (up to 0.7). This means that about 34% of individuals constituting this group have an internal environment reliability that corresponds to an age between 5-9 years and 10-14 years. Moreover, about 14% of individuals making up the 10-14 year group have a 0.4-0.7 relative HKP size, i.e., they have a reliability that corresponds to the age group below the 5-9 year interval. Very few individuals of the 10-14 year group (slightly more that 2%) have a 0.1-0.4 relative HKP size, that is, their reliability corresponds to an age of about 1-4 years.
>
> (2) Similarly, in groups with the lowest reliability (ages below 1 year and the 60-64 year group), there are a small number of individuals that have a higher reliability of the organism's internal environment.

Thus, the reliability of the organism's internal environment strongly depends on the individual features of a person. There is a so-called variability of individual reliability of the human organism. This variability must be taken into consideration when estimating the death risk due to unreliability of the body's internal environment.

According to the concepts being developed here, there is also a similar variability of organism's resistance to any external factors. In other words, there is a variability of the human organism's sensitivity to the adverse effects of the external environment.

2.3 AGE DEPENDENCE OF DISEASE-RELATED DEATH RISK

The dependence of the risk of death on age demonstrates certain trends in the formation of the organism's internal environment. This can be seen from the data (Table 2.2) obtained by averaging the WHO indices of mortality from diseases for males of five countries of the world: USA, Sweden, Czechoslovakia, Great Britain, and France (8).

The average annual risk of death from diseases is about 1%. The data demonstrate a high age dependence of this particular type of death risk. For instance, on passing from the 10-14 year group to the 55-59 year group the death risk increases 75-fold. The minimum annual risk of death from disease is 2×10^{-4}, or 2×10^{-2} percent. The disease-related death risk data from Table 2.2 will be used later for comparison with the corresponding data for Russia.

Figure 2.1 shows the age dependence of the disease-related death risk for Russia. These data refer to both sexes and include their respective contributions to the total number of the population (47.8% males, 53.2% females). Data for 1989 were used, as this was the last year of relatively stable social-demographic situation. The mean expected life duration in that year was nearly 69 years. One can see that the minimal annual risk of death in these conditions was about 4×10^{-4} per person, which is twice as high as the minimal risk from Table 2.2. Also, the death risk for men was nearly twice as high as it was for women. The difference in death risk between males and females in all age groups, especially in recent years, exerted a very considerable effect on the ratio of sexes (see Supplement, Table 2.5), that is, on the demographic structure of the Russian population. The demographic structure of the population should be taken into account in assessing risks of various harmful effects.

Obviously, the reliability of the human organism even in the most resistant age groups of the adult population may prove to be insufficient for some high-responsibility jobs, such as operators of an energy system, pilots, astronauts, etc. In such cases, a special selection procedure by medical indications oriented to the specific features of a particular high-responsibility job is used. Medical selection makes it possible to obtain a relatively small professional group of operators (civil aviation pilots, military pilots, astronauts, etc.) whose organisms' reliability and resistance to the effects of specific occupational risks are especially high. Our estimates have shown that the annual risk of death from disease for operators of high-responsibility professions can be reduced by an adequate medical selection procedure to 10^{-4} for pilots and to 10^{-5} for astronauts. The effectiveness of such a selection is based on the concept of variable reliability of the human organism set forth in the preceding section.

2.4 RISK OF DEATH FROM DISEASE FOR THE RUSSIAN POPULATION

The Russian population mortality has at present a definite tendency toward rising. While in 1985 1.6 million persons died, in 1992 this number was already 1.8 million and in 1993 it was 2.1 million (of which 620,000 died at an economically active age). In 1995, the annual risk of disease-related death was 1.56×10^{-2} (3).

Among the main causes of death, first place belongs to the cardiovascular diseases (1.1 million cases) and second place to malignant tumors (0.3 million cases). The cardiovascular diseases resulting in death can be divided into three major groups: ischemic heart diseases, cerebrovascular disorders, and non-hypertensive cardiosclerotic atherosclerosis.

Particularly dangerous for the Russian population is the recent increase of the incidence rate of infectious diseases. An emergency situation with diphtheria (a 25-fold increase in morbidity and a 4.4-fold increase in mortality compared to 1988) had developed by 1993. That year the total mortality due to all infectious diseases reached 17.3 per 100,000 persons.

The death risk for infants in the first 12 months of life decreased with small variations from 22.1 in 1980 to 17.4 in 1990 per every thousand live births. The infant death risk started growing in 1991 and reached 19.9 x 10^{-3} in 1993. For comparison, the infant mortality in the same year was 8.6 in the USA, 7.3 in France, and 4.4 in Japan per 1,000 live births. A more detailed examination of infant mortality from different causes can be found in Section 7.

The increase in the Russian population mortality was mainly due to the contribution of economically active ages. While the total number of deaths in 1993 was greater than that in 1990 by 29%, among the economically active groups the increase was 1.5-fold. The mortality of economically active males is four times that of females. The deplorable situation with mortality among the economically active population and infants became the principal factor of the reduction of life expectancy from 70 years in 1987 to 65 years in 1993. For comparison, life expectancy was 75 years in the USA, 77 years in Canada, 78 years in Sweden, and 79 years in Japan. This point is dealt with in greater detail in Section 8.

To make the mortality rate data for Russia easier to interpret and compare with the data from other countries, use has been made of mortality indices standardized according to the European age structure by main classes of death causes (Table 2.3) (1). In this table, the column "All causes" includes only diseases, because other causes of death, such as injuries or poisonings, are considered separately in Section 4.

The situation with increased death risk for the Russian population in 1993 is not just a result of an unlucky concurrence of circumstances. It is a stable trend that had started to manifest itself around 1989. The risk of death from a disease increases at an increasing rate, as is true for practically every other principal cause of death. For instance, the annual risk of death from the cardiovascular diseases had a minimum in 1988 followed by a sharp growth, so that in 1993 this particular risk was 7.83 x 10^{-3} per person. Over the same time period, the annual risk of death from cancer increased gradually and in 1993 reached 2.07 x 10^{-3} per person, which is about 20% higher than the level of 1981.

The **total annual risk of death** from any disease for a Russian resident in 1993 reached 1.25 x 10^{-2}, which is about 1.3 times that given in Table 2.2 for prosperous countries. As pointed out at the beginning of this section, in Russia the annual risk of death from disease alone reached the level of 1.56 x 10^{-2} per person in 1995; that is, it continued to increase steadily. The situation with mortality in Russia will appear even worse if other sources of death risk, which are discussed in Sections 3.0 through 7.0, are taken into account.

Mortality from such causes as most cardiovascular diseases or tumors can be regarded as death from natural causes (7), as these are diseases of old age. What looks rather grim is the phenomenon of rejuvenation of this particular type of mortality in present-day Russia: an ever increasing number of comparatively young people die prematurely before they reach old age (7). This tendency has a significant effect on the average lifetime data (see Section 8).

In principle, chronic diseases attacking people in old age should gradually substitute as the causes of death instead of other causes of death that are removable (7).The strategy of control of disease-related death risk must be aimed at enlarging the contribution of removable death causes and at displacing the non-removable death causes toward the oldest possible ages (7). In most developed

countries, this strategy has proved to be successful and the mortality from removable causes has indeed diminished (7). This, however, cannot be said of Russia: a considerable increase of death rate from many removable causes was recorded in 1992-1993 (Table 2.4) (7).

2.5 RISK OF DEATH FROM DISEASE FOR DIFFERENT TERRITORIES OF RUSSIA

For a long time the principal feature of regional distribution of mortality over the Russian territories has been the so-called "north-east gradient" (7). This means that in Siberia and the Far East, in the northern part of the Urals territory, and in the northern part of European Russia the population mortality is much higher than in the North Caucasus, Volga Regions, and the Central Black Earth Region. The central part of the country occupies an intermediate position in this territorial distribution. The dramatic increase of mortality in 1993 brought about an increase in the north-east gradient (7).

Two relatively independent factors are known to basically affect the general mortality rate: the age-specific mortality rate and the age structure of the population of a particular region. The population age structure differs considerably from region to region in the Russian Federation, which precludes the utilization of general mortality rates for Russia as a whole.

The distribution of the annual risk of disease-related death over the territory of Russia in 1992 was as follows (1).

<u>Below 7.7×10^{-3} per person</u>:
Dagestan (North Caucasus) and Koryak Autonomous Area (the northern Kamchatka Peninsula), which are regions of low economic development and low levels of alcoholism.

<u>7.7×10^{-3} to 9.1×10^{-3} per person</u>:
Murmansk and Tyumen regions; Yakutia, Kalmykia, Checheno-Ingush and Kabardino-Balkar republics.

<u>9.1×10^{-3} to 10.6×10^{-3} per person</u>:
Udmurt, Mariy-El, Tuva, Chuvashia, Buryat, and Komi republics; Tomsk, Chita, Amur and other regions of Siberia and the Russian Far East.

<u>10.6×10^{-3} to 12.1×10^{-3} per person</u>:
Primorski, Altai, and Krasnoyarsk territories; Irkutsk, Novosibirsk, Volgograd, Astrakhan, and some other regions.

<u>12.1×10^{-3} to 13.6×10^{-3} per person</u>:
Leningrad, Yaroslavl, Perm, Sverdlovsk, Saratov and other regions of European Russia, and also the Kurgan region.

<u>13.6×10^{-3} to 15.0×10^{-3} per person</u>:
Moscow region (except the city of Moscow), Vladimir, Bryansk, Smolensk and other European regions of Russia.

15.0 x 10^{-3} to 16.6 x 10^{-3} per person:
Novgorod, Pskov, Tver, Tula, Tambov, and Ivanovo regions of the Central European part of Russia, and the city of Moscow.

2.6 CONCLUSIONS

We have considered the first source of death risk, according to our classification given in Section 1. This source resides in the human organism itself and is due to the unreliability of organism's internal environment. The total lifetime risk is unity. The question is how the death risk, which is referred to a unit of time (e.g., a year), is distributed over the average human lifetime. In other words, what is the age dependence of the death risk?

The age dependence of the death risk includes three major sections: (1) the section of drastic decline of death rate (formation of the homeokinetic plateau), i.e. the age range from 0 to 5 years; (2) the section of a relatively constant and minimal death rate (maximal size of the homeokinetic plateau), the age range from 5 to 30 years; and (3) the section of sharply increasing death rate (reduction of the homeokinetic plateau), or the age range from 30 years upward.

This dependence is an extremely important characteristic of a population: it reflects its evolution, the effects of environmental conditions, and the variation of these conditions over the life spans of many generations. The death risk associated with the effects of the natural and man-made environment, professional and other activities, and of social conditions generally makes only a small contribution to the disease-related death risk corresponding to a given age. The latter is generally used as a yardstick when comparing the effects of other sources of hazard.

The approach we propose regards the sex and age dependence of the risk of death from diseases to be the basic characteristic of any population, and all the effects of external factors represent perturbations that manifest themselves at various sections of this dependence. This justifies our attempts to consider separately the contributions of other sources of death risk for man: the natural environment, the man-made environment, professional activity, nonprofessional activity, and the social environment.

Among the problems associated with the reliability of the organism's internal environment that still await their solution is the problem of individual variability of this environment. Any case study of risk of death from disease for a particular region or a time period will require knowledge of the type of the distribution of individual sensitivity as a function of age for different human diseases. It is also necessary to develop methods for identifying the so-called high-risk groups with respect to these diseases.

Table 2.1: The average relative size of the homeokinetic plateau (HKP).

Age Groups (Years)	< 1	1-4	5-9	10-14	15-19	20-24	25-29	30-34	40-44	50-54	60-64
Size of HKP	0.009	0.25	0.67	1.00	0.67	0.50	0.40	0.22	0.07	0.02	0.008

Table 2.2: The individual annual risk of death from disease.

Age Groups	Risk of Death (x 10^{-2})
All ages	1.05
0	2.30
1-4	0.08
5-9	0.03
10-14	0.02
15-19	0.03
20-24	0.04
25-29	0.05
30-34	0.09
35-39	0.16
40-44	0.27
45-49	0.48
50-54	0.84
55-59	1.50
60-64	2.50
65-69	3.80
70-74	5.90
75-79	9.10
80-84	14.30
85 ~~and~~ older	24.00

Table 2.3: Individual annual risk of death (x 10^{-5}) from diseases in 1981-1993 for the population of Russia.

Years	All Causes (Diseases)	Cardio-vascular Diseases	Malignant Tumors	Respiratory Diseases	Gastro-intestinal Diseases	Infectious & Parasite Diseases	Perinatal Diseases
1981	1067.6	695.7	167.9	96.4	32.5	20.6	9.7
1982	1032.5	674.1	170.4	85.0	31.7	19.0	9.7
1983	1056.9	693.7	172.8	85.4	33.1	18.3	10.2
1984	1099.9	729.4	172.7	87.7	33.7	18.5	11.0
1985	1086.4	718.7	173.2	86.1	32.5	17.6	12.6
1986	945.7	657.5	177.4	66.9	28.7	14.5	13.3
1987	947.7	657.4	179.3	64.1	29.1	13.9	14.0
1988	934.5	543.2	195.1	61.1	27.8	14.6	12.4
1989	1032.5	664.3	201.7	62.7	29.3	13.2	12.3
1990	1057.0	668.7	203.8	63.2	30.1	12.8	12.7
1991	1054.5	658.5	204.8	58.8	30.1	12.7	12.5
1992	1090.7	675.3	206.4	60.6	33.7	13.9	12.4
1993	1246.6	782.9	207.4	76.4	38.9	18.4	13.2

Table 2.4: Risk of death from removable causes in 1965-1993 in Russia (x 10^{-3}).

Cause of Death	1965	1985	1990	1993
Males				
Respiratory diseases	1.51	1.58	1.19	1.50
Bronchitis and emphysema	0.36	0.52	0.62	0.69
Pneumonia	0.31	0.26	0.15	0.30
Tuberculosis	0.62	0.22	0.17	0.26
Asthma	0.07	0.06	0.08	0.09
Gastrointestinal diseases	0.39	0.51	0.45	0.60
Peptic ulcer	0.05	0.09	0.08	0.13
Infectious and parasitic diseases	0.72	0.30	0.22	0.33
Genitourinary diseases	0.22	0.22	0.21	0.21
Hypertension diseases	0.23	0.09	0.09	0.12
Rheumatism	0.25	0.09	0.07	0.08
Diabetes	0.02	0.03	0.05	0.07
Females				
Respiratory diseases	0.68	0.56	0.36	0.42
Gastrointestinal diseases	0.22	0.23	0.22	0.27
Bronchitis and emphysema	0.14	0.17	0.17	0.16
Uterine cancer	0.21	0.14	0.14	0.14
Diabetes	0.02	0.04	0.07	0.10
Hypertension diseases	0.18	0.07	0.08	0.10
Pneumonia	0.20	0.11	0.07	0.09
Genitourinary diseases	0.07	0.09	0.09	0.09
Rheumatism	0.25	0.10	0.08	0.09
Infectious and parasitic diseases	0.23	0.09	0.06	0.07
Asthma	0.03	0.04	0.04	0.05

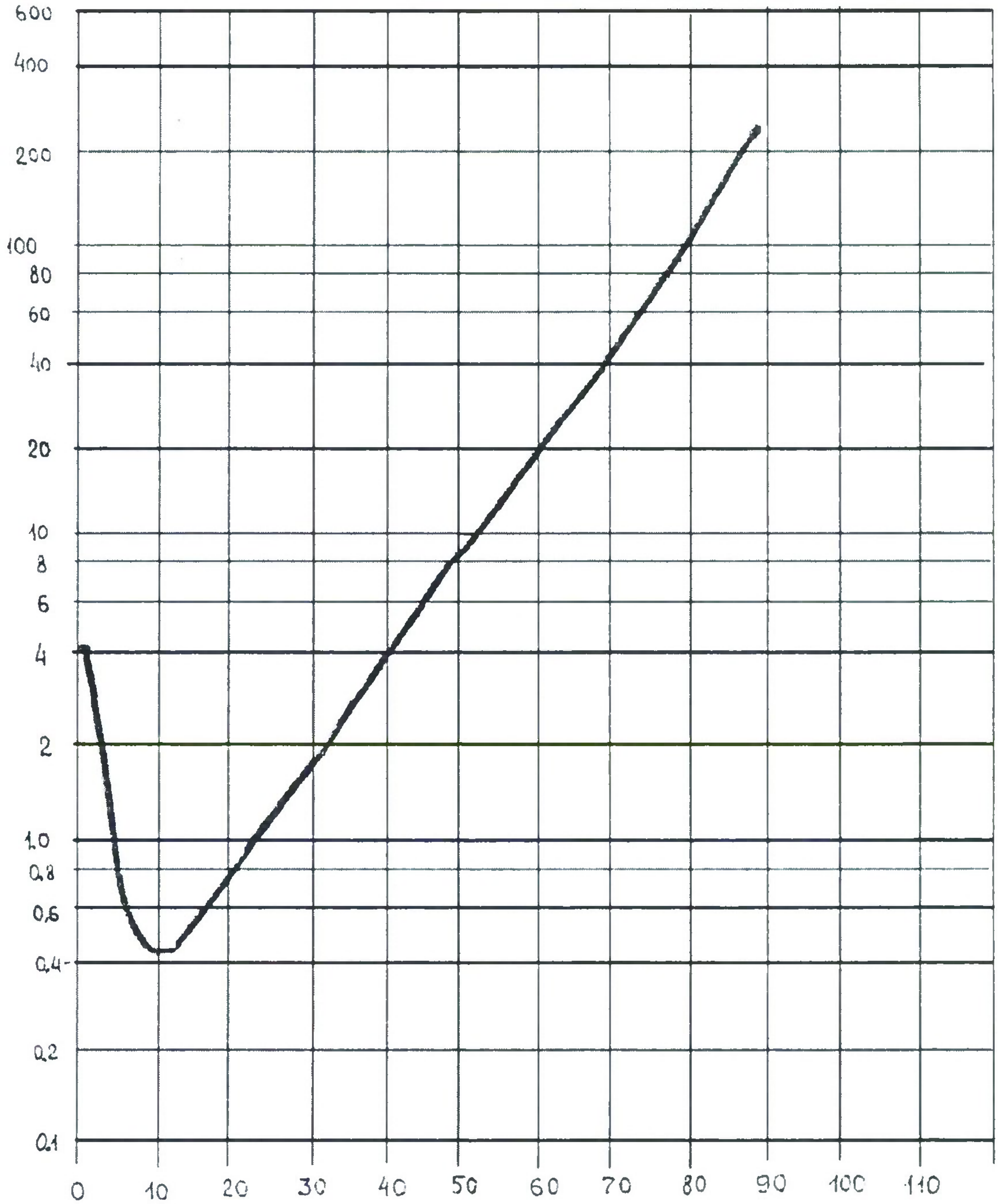

Figure 2.1: Age dependence of the risk from death from disease for the population of Russia.

Table 2.5: Male-female distribution by age groups of the Russian population, 1939-1994.

Age Groups, Years	1939 1959		1979 1989	1993		1994
Whole population	1120	1242	1174	1140	1131	1130
0-4	983	963	969	963	953	950
5-9	1010	969	971	969	965	963
10-14	1008	971	971	972	971	970
15-19	1052	994	946	947	975	974
20-24	1116	994	963	968	934	929
25-29	1059	1017	974	970	978	979
30-34	1028	1198	988	987	988	987
35-39	1198	1196	1053	1007	1007	1010
40-44	1225	1622	1069	1029	1031	1034
45-49	1287	1672	1110	1112	1066	1068
50-54	1263	1752	1347	1154	1170	1174
55-59	1665	2207	1919	1258	1227	1236
60-64	1556	2087	2010	1581	1383	1385
65-69	1684	2144	2226	2298	1907	1783
70 and older	1942	2493	3095	3125	3132	3129
Urban residents	-	-	-	-	-	-
0-4	-	-	-	-	-	-
5-9	1110	1228	1170	1145	1137	1137
10-14	982	962	966	961	952	949
15-19	1010	970	968	967	962	961
20-24	1026	980	971	971	969	968
25-29	1084	1035	1024	986	999	995
30-34	1212	1043	1006	988	925	927
35-39	992	1022	1004	1001	1000	991
40-44	998	1170	1006	1026	1025	1022
45-49	1178	1597	1056	1044	1046	1050
50-54	1170	1495	1086	1054	1067	1072
55-59	1163	1504	1131	1123	1085	1093
60-64	1182	1623	1315	1179	1186	1188
65-69	1426	2007	1893	1293	1258	1265
70 and older	1620	2053	1896	1559	1418	1429
Rural residents	1939	2185	2100	2278	1873	1755
0-4	2509	2856	3047	2971	2982	2987
5-9	-	-	-	-	-	-
10-14	-	-	-	-	-	-
15-19	1126	1258	1183	1125	1116	1113
20-24	984	964	974	968	956	953
25-29	1010	968	975	974	972	970
30-34	1001	961	970	972	975	975
35-39	1033	947	778	826	908	917
40-44	1119	930	845	909	965	938
45-49	1110	1010	885	882	917	945
50-54	1047	1238	924	872	887	893
55-59	1211	1595	1045	885	891	894
60-64	1259	1807	1028	936	908	910
65-69	1361	1910	1067	1079	992	975
70 and older	1310	1915	1415	1091	1128	1135

Table 2.6: Mortality of the Russian population in 1960-1993 (individual annual risk of death, x 10^{-3}).

Years Whole	Population	Urban Residents Ru	ral Residents
1960	7.4	6.7	8.2
1965	7.6	6.9	8.6
1970	8.7	7.9	10.0
1975	9.8	8.8	11.8
1980	11.0	10.0	13.4
1985	11.3	10.3	14.0
1986	10.4	9.6	12.5
1987	10.5	9.7	12.7
1988	10.7	9.9	13.0
1989	10.7	10.0	12.7
1990	11.2	10.4	13.3
1991	11.4	10.6	13.4
1992	12.2	11.5	14.1
1993	14.5	13.8	16.4

Table 2.7: Comparison of population mortality in Russia and other countries in 1990 and 1992 (individual annual risk of death, x 10^{-3}).

Country 1990		1992
Russia	11.2	12.2
Australia	7.0	7.1
Austria	10.6	10.5
Belgium	10.6	10.6
Bugaria	12.1	12.1
Great Britain	11.2	11.3
Germany	11.2	11.1
Denmark	11.9	11.8
Canada	7.2	7.2
China	6.7	6.6
Netherlands	8.6	8.6
Norway	10.7	10.4
Poland	10.1	10.3
Romania	10.6	10.6
USA	8.6	8.5
Finland	10.0	9.8
France	9.3	9.1
Switzerland	9.5	9.1
Sweden	11.1	10.9
Japan	6.7	6.7

Table 2.8: Age coefficients of mortality for the Russian population (individual annual risk of death, x 10^{-3}).

I. Males						
Age Group, Years	**1970-1971**	**1985-1986**	**1990**	**1991**	**1992**	**1993**
All Ages	9.4	11.0	11.6	11.9	13.1	16.1
0-4	6.5	6.0	4.4	4.4	4.3	4.5
5-9	0.9	0.7	0.7	0.8	0.7	0.7
10-14	0.7	0.6	0.6	0.7	0.7	0.7
15-29	1.6	1.4	1.6	1.7	1.8	2.1
20-24	2.7	2.5	2.6	2.7	3.2	3.8
25-29	4.0	3.0	3.3	3.5	4.2	5.1
30-34	5.0	3.9	4.3	4.5	5.5	7.0
35-39	6.6	5.0	5.6	5.9	7.1	9.3
40-44	8.2	8.1	7.6	8.0	9.8	13.3
45-49	10.9	10.7	11.7	11.6	13.5	17.8
50-54	15.1	16.2	16.1	16.5	19.4	25.3
55-59	21.0	22.7	23.4	23.3	25.3	31.3
60-64	31.2	32.8	34.2	34.6	36.9	45.3
65-69	46.5	48.0	46.6	47.3	49.4	59.4
70 and older	102.6	97.6	103.6	104.0	105.7	118.8
II. Females						
Age Group, Years	**1970-1971**	**1985-1986**	**1990**	**1991**	**1992**	**1993**
All Ages	8.1	10.7	10.9	11.0	11.4	13.0
0-4	4.9	4.4	3.3	3.2	3.1	3.5
5-9	0.5	0.4	0.4	0.4	0.4	0.4
10-14	0.4	0.3	0.3	0.3	0.3	0.4
15-29	0.6	0.5	0.6	0.7	0.7	0.8
20-24	0.8	0.6	0.7	0.7	0.8	1.0
25-29	1.0	0.8	0.8	0.9	1.0	1.2
30-34	1.3	1.1	1.1	1.1	1.3	1.6
35-39	1.9	1.6	1.6	1.6	1.9	2.4
40-44	2.6	2.6	2.4	2.5	2.8	3.7
45-49	3.9	3.6	3.8	3.8	4.2	5.4
50-54	5.9	5.9	5.4	5.5	6.1	7.9
55-59	8.1	8.8	8.6	8.6	9.1	10.9
60-64	13.0	13.8	13.5	13.6	14.4	16.7
65-69	21.3	22.7	22.0	22.0	22.5	25.6
70 and older	71.5	70.6	77.9	78.1	79.6	87.6

Table 2.9: Mortality of the Russian population due to principal causes of death (individual annual risk of death, x 10^{-5}).

Cause of Death	1990	1991	1992	1993
All causes	1116.7	1137.5	1215.6	1446.4
Infectious and Parasitogenic diseases	12.1	12.0	13.1	17.3
Neoplasms	194.0	197.5	201.8	206.9
Malignant tumors	191.8	195.5	199.7	204.6
Cardiovascular diseases	617.4	620.0	646.0	768.9
Respiratory diseases	59.3	55.7	57.9	74.5
Gastrointestinal diseases	28.7	28.9	32.8	38.3
Genitourinary diseases	11.4	11.4	11.8	12.2
Diabetes	6.3	7.0	7.6	8.9
Disease of the nervous system and sense organs	7.0	7.5	8.1	9.9

Table 2.10: Population mortality in various territories of the Russian federation (individual annual risk of death, x 10^{-3}).

Territories of Russia	Risk of Death
Russian Federation	14.5
Northern area	13.3
Karelian republic	14.8
Komi republic	11.8
Arkhangelsk region	14.3
Vologda region	15.3
Murmansk region	10.1
Northwestern area	17.9
St. Petersburg	17.4
Leningrad region	17.9
Novgorod region	18.8
Pskov region	20.4
Central region	16.6
Bryansk region	15.9
Vladimir region	15.7
Ivanovo region	17.0
Kaluga region	15.8
Kostroma region	16.0
Moscow	16.5
Moscow region	16.0
Orel region	16.0
Ryazan region	17.1
Smolensk region	16.5
Tver region	19.4
Tula region	18.4
Yaroslavl region	17.1
Volga-Vyatka area	14.6
Mariy-El	12.6
Mordovia	13.7
Chuvashia	12.4
Kirov region	14.6
Nizhni Novgorod region	16.1
Central Black Earth area	16.3
Belgorod region	15.4
Voronezh region	16.6
Kursk region	16.6
Lipetsk region	15.5
Tambov region	17.4
Volga area	13.4
Kalmykia	9.9
Tatarstan	11.9
Astrakhan region	13.0
Volgograd region	13.8
Penza region	15.1
Samara region	13.8

Table 2.10 (Continued)	
Saratov region	14.6
Ulyanovsk region	13.0
Northern Caucasus	13.6
Adygeya	14.9
Dagestan	7.6
Kabardino-Balkaria	10.0
Karachai-Cherkessia	10.0
North Ossentia	12.1
Krasnodar territory	15.7
Stavropol territory	13.3
Rostov region	15.0
Urals	13.8
Bashkiria republic	12.5
Udmurtia republic	13.4
Kurgan region	14.5
Orenburg region	12.7
Perm Region	14.7
Sverdlovsk region	15.1
Chelyabinsk region	13.6
Western Siberia	13.0
Altai republic	13.3
Altai territory	14.0
Kemerovo region	15.3
Novosibirsk region	14.1
Omsk region	11.9
Tomsk region	13.4
Tyumen region	9.5
Eastern Siberia	13.0
Buryatia	11.7
Tuva republic	11.4
Khakassia	14.4
Krasnoyarsk territory	13.5
Irkutsk region	13.3
Chita region	12.0
The Far East	11.8
Yakutia (Sakha)	8.8
Jewish Autonomous	12.8
region	7.6
Chukot Autonomous area	13.0
Primorski territory	12.4
Khabarovsk territory	12.0
Amur region	9.9
Kamchatka region	11.1
Magadan region	12.1
Sakhalin region	42
Kaliningrad region	13.5

3.0: NATURAL ENVIRONMENT AS A SOURCE OF DEATH RISK

3.1. INTRODUCTION

The effects of the natural environment on man are known to be very diverse. They include earthquakes, hurricanes, floods, storms, volcanic eruptions, thunderbolts, bites and stings by venomous insects and other animals, etc. In our attempts to estimate the risk of damage inflicted by the natural environmental factors, we have encountered serious difficulties in view of the fact that the published data mainly concern very rare and very destructive events which bring about devastating aftereffects. At the same time, there is quite insufficient information on casualties in events which are frequent but do not involve many victims. Natural cataclysms form a continuous spectrum of events. The frequency of these events increases roughly exponentially as the magnitude of a single event decreases. The aftereffects of natural disasters depend appreciably on the age of the people involved. The aftereffects are minimal for the 5-9, 10-14, 15-19, 20-24, and 25-29 year age groups. Most victims of emergency situations are infants, small children and old people. This is in good correlation with the age dependence of the relative average size of the homeokinetic plateau for man. As indicated in Section 2.2, the size of this plateau is related with the reliability of the organism's internal environment and its resistance to the action of external factors.

This section deals with the effects of natural disasters over the Russian territory, and the extent and geography of death risk in such events. Use was made of data published mainly in 1994-1996 (1-9).

3.2. NATURAL CATACLYSMS ON RUSSIAN TERRITORY

Russia is subject to the whole range of dangerous natural disasters and processes of geological, hydrological, and meteorological origins. More than 30 types of dangerous natural processes and phenomena are observed every year in Russia, and their development into natural disasters and cataclysms brings enormous material losses and many human deaths (3, 5). Here is the list of emergency situations (ES) caused in recent years by dangerous natural phenomena over the territory of Russia (in percentage of total) (3).

Floods	35
Hurricanes, storms, typhoons, tornadoes	19
Torrential rains	14
Earthquakes	8
Snowfalls, snowstorms	7.5
Landslides, landslips	5
Excessive frost	3
Avalanches	2.5
Droughts	2
Icy crusts, karst collapses	1
Volcanic eruptions	< 1
Others	about 5

In 1993, there were 245 emergency situations due to cataclysms on the Russian territory, and they took the lives of 89 persons. In 1994, 94 persons lost their lives in 278 ES. In 1995, 2000 persons died in 205 ES (mainly in the Sakhalin earthquake of May 27, 1995).

About 20% of the Russian territory is subjected to earthquakes of magnitude exceeding 7. More than 5% of this area is high-risk zones exposed to magnitude 8-9 earthquakes. These include the North Caucasus, Baikal areas, Yakutia, Sakhalin, Kamchatka, and the Kuril Islands. More than 20 million persons in Russia live under the risk of devastating earthquakes. There were 36 strong earthquakes (mainly on Kamchatka and Sakhalin) in 1993 and 163 such events in 1994. The most destructive earthquake in Russian history occurred on May 27, 1995 on Sakhalin Island.

Disastrous floods rank first among cataclysms with respect to recurrence, the area involved, and the damage produced. The death toll is also high: 18 deaths in 1993 and 40 in 1994. Volcanic eruptions are a serious threat to the population of Kamchatka and the Kuril Islands. There are 29 volcanoes at a dangerous stage of activity on Kamchatka and 39 on the Kuril Islands. Several towns of Kamchatka and 25 settlements of the Kuril Islands are located in the high-risk zones.

Tsunami represent a considerable environmental hazard for the coastal residents of the Far East. Over the last 90 years, about 20 dangerous tsunami have been observed at the Russian coasts. In 1952, tsunami destroyed the town of Severo-Kurilsk. Nine Russian towns are situated within the tsunami high-risk zone.

Cataclysms associated with strong winds (typhoons, hurricanes, and tornadoes) of velocities exceeding 20 m/s (over 40 knots) can occur practically over the entire Russian territory. About 500 cities are subjected to hurricane winds and tornadoes. The damage inflicted by strong winds is comparable to that of floods.

Every year Russia suffers from 10,000 to 30,000 forest fires. Seasons of particularly high hazard of extensive forest fires occur two to three times every ten years. The most extensive fires take place in sparsely populated regions of Siberia and the Far East. The European part of Russia suffers from peat bog fires, which often occur in the vicinity of settlements. Only 20% of forest fires are of natural origin.

Hazardous geological processes (landslides, mud flows, etc.) are also very widespread over the Russian territory, particularly in the North Caucasus, Volga regions, Sakhalin, Transbaikalia, and Altai. There 70-80% of the territory is affected. Nearly 10,000 cities and large settlements of Russia suffer from these geological phenomena. About 18% of the Russian territory is exposed to the hazard of avalanches. In 1993 avalanches took 68 lives.

3.3 EMERGENCY SITUATIONS OF NATURAL ORIGIN IN VARIOUS RUSSIAN REGIONS

The territory of Russia is very nonuniform with respect to frequency of emergency situations of natural origin, the effects of these situations on the population, and the losses incurred. Analysis of direct hazard to life and health from natural environmental factors made possible a comparison of Russian regions by the frequency of occurrence of ES of natural origin (4). The number of ES per

unit area and the number of ES per unit population were used as criteria. To characterize the extent of risk of cataclysms for the public use was made of a combined index: the ES frequency. This index is defined as the mean value between the number of ES per unit area and the number of ES per unit population number, both expressed as percentages of the maximal level for Russia. The obtained data on the frequency of ES of natural origin refer to 1989-1993 (4). The regions of Russia can be grouped according to the natural ES frequency index in the following way.

"Safe" Regions:

Frequency index < 1:
Vologda and Kirov regions.

Frequency index 1-2.5:
Altai, Yakutia, and Komi republics; Lipetsk, Orenburg, Perm, Nizhni Novgorod, Bryansk, Tyumen, Omsk, and Kemerovo regions; Altai territory.

Frequency index 2.5-3.3:
Magadan, Amur, Irkutsk, Tomsk, Arkhangelsk, Kurgan, Samara, Penza, Tula, Ivanovo, Kostroma, and Yaroslavl regions; Khabarovsk territory.

Frequency index 3.3-8.0 ("relatively safe"):
Chuvashia, Khakassia, Kalmykia, Tuva, Udmurtia, Buryatia, and Karelia republics; Chita, Novosibirsk, Leningrad, Chelyabinsk, Moscow, Vladimir, Ryazan, Tombov, Voronezh, Volgograd, and Rostov regions; Krasnoyarsk territory.

"Unsafe" Regions:

Frequency index 8.0-16.0 ("relatively unsafe"):
Bashkiria, Tatarstan, Mariy-El, Mordovia, and Checheno-Ingush republics; Sakhalin, Murmansk, Sverdlovsk, Ulyanov, Saratov, Astrakhan, Kaliningrad, Tver, Pskov, Smolensk, and Kaluga regions; Khabarovsk and Stavropol territories.

Frequency index 16.0-32.0:
Dagestan, North Ossetia, Kabardino-Balkaria, and Adygei republics; Kamchatka and Novgorod regions; Krasnodar territory.

Frequency index 32.0-63.0 ("highly unsafe"):
Karachai-Cherkess republic.

A permanently elevated level of hazard of cataclysms is specific to the Caucasus regions. The population density there is quite high in highlands exposed to avalanches and mud torrents, and in zones of seismic activity. In mountainous areas of Siberia and the Urals, natural cataclysms are less frequent, though they still represent a considerable hazard. The ES frequency is at its maximum in the active volcano zone of Kamchatka. Fortunately, the North Caucasus and Kamchatka belong to the least populated territories (less than 700,000 permanent residents).

In plain localities, the frequency of dangerous natural phenomena is somewhat lower, especially within forest and forest-steppe zones.

3.4 EXTENT OF DEATH RISK DURING NATURAL CATACLYSMS

Rough estimates of the risk of death during cataclysms have been calculated using data on the average annual frequency of these events and the average number of victims per event. These data refer to residents of plain areas of the forest and forest-steppe zones outside regions of increased seismic activity, volcanism, etc., that is, to the populations of safe (frequency index 2.5-3.5) and relatively safe (frequency index 3.3-8.0) territories of Russia. One can tentatively assume that the rough estimates of risk of death in cataclysms correspond to a frequency index of 3.3 at the boundary between safe and relatively safe territories.

Table 3.1 gives approximate estimates of risk of death during natural cataclysms (9). Thus, the total individual annual risk of death from the natural environmental factors is 1.0×10^{-5}. Comparison with the risk of death from disease (Section 2.0) reveals that this is no more than 1/20 of the minimal (in the 10-14 year age group) mortality rate per individual, and no more than 1/10,000 of the mortality rate for the whole population. Recall that these estimates of total risk refer only to safe and relatively safe territories.

For the category of unsafe (with respect to natural ES) regions (mean frequency index 24.0), the individual annual risk of death is about 7×10^{-5}. For the group of highly unsafe regions (mean frequency index 48.0), the individual annual death risk reaches 1.5×10^{-4}.

The maximal individual annual risk of death from natural environmental factors for Russian regions (minimal frequency index of 100) is about 3×10^{-4}. This value approaches the minimal individual mortality rate (in the 10-14 year group).

3.5 CONCLUSIONS

Virtually all known natural cataclysms occur from time to time over the Russian territory. The regions, however, differ considerably in the incidence of occurrence of dangerous cataclysms: the ES frequency index varies from a value less than unity in the most "safe" regions to 63 in the highly "unsafe" ones.

A permanently elevated level of hazard from natural disasters is specific for the Caucasus and Kamchatka regions. In the plain areas of Russia this hazard is somewhat lower. Estimates have shown that the total individual annual risk of death in cataclysms for highlands is 1.5×10^{-4}, whereas for the plain regions it is 1×10^{-5}.

Unfortunately, in view of the lack of necessary statistical data, we are unable to assess the risk of death from cataclysms for each age group separately. Qualitative estimates definitely indicate that this risk is highly dependent on age: it is minimal in the 10-14 year group but can reach high values in the infant and old-age groups. This point, however, requires further quantitative studies.

In the future, serious attention should be given to natural disasters induced by human technogenic

activity. For example, the question of so-called induced earthquakes requires separate consideration. Even in seismically quiet regions, intensive and careless exploitation of the lithosphere increases the seismic hazard. In particular, technogenic seismicity arises as a result of digging large artificial reservoirs, mining, building large hydroelectric stations, pumping water into oil wells, large-scale industrial and military explosions, and other intensive surface and underground work (3). Unfortunately, no purposeful collection of statistical data on induced earthquakes and the damage and victims involved has been conducted in Russia to date (3).

Table 3.1: Individual annual risk of death from natural cataclysms.

	Cataclysm Type	**Risk of Death**
1	Floods	4×10^{-6}
2	Earthquakes	2×10^{-6}
3	Typhoons, hurricanes, storms	2×10^{-6}
4	Thunderstorms	2×10^{-6}
	Total	1.0×10^{-5}

4.0: MAN-MADE ENVIRONMENT AS A SOURCE OF DEATH RISK

4.1 INTRODUCTION

The development of human civilization created particular living conditions which together make up what can be called the man-made environment. The man-made environment makes it possible for man to be practically independent of adverse effects of many natural phenomena and provides conditions for further development of civilization. At the same time, the man-made environment is responsible for the appearance of new sources of danger for humans and, accordingly, for an increase of individual risk of death.

Present-day man-made environment is absolutely the result of human technogenic activity and therefore can also be called the "technogenic environment." The risk of death related to the technogenic environment can therefore be called the technogenic risk. Effects of the man-made environment on the population are highly diversified. They include all accidents and misadventures indoors and outdoors, in any kind of transport (for passengers), diseases and mortality due to the pollution of air, water, and soil by industrial, transport, and agricultural toxic products and wastes.

In writing this chapter, use was made of data pertaining to the Russian population and published mainly in 1993-1996 (1-10).

4.2 PRINCIPAL PATHWAYS OF INFLUENCE OF THE MAN-MADE ENVIRONMENT ON THE POPULATION

These pathways are as follows.

1. Air pollution.
2. Water and soil pollution.
3. Indoor, road, and transport accidents.
4. Technogenic emergency situations.

4.2.1 AIR POLLUTION WITH INDUSTRIAL WASTES

The principal air pollutants traditionally are generated by large industrial plants. Beginning with 1991, the deterioration of the general economic situation in Russia and the overall decline of industrial activity led to a decrease in air pollution of large cities. The total noxious releases to the atmosphere reduced from 34 million tons in 1990 to 28 million tons in 1992. This reduction brought about a decrease of mortality from respiratory diseases beginning in 1991 (1). Nevertheless, the level of air pollution remained high. The average annual concentrations of noxious substances in the air of many (about 230) cities exceed the maximum permissible concentrations (MPC) for the public established in Russia. Of particular concern is the problem of high concentrations of carcinogenic agents in the exhaust gases of motor vehicles, which grow from year to year (1, 8). The maximal concentrations of many noxious substances are as high as five times the MPC in more than 150 cities and ten times the MPC in 86 cities. The number of residents exposed to five times the MPC of various health-damaging substances is 54.9 million and those exposed to ten times the MPC is 40.1

million. More than 66 million individuals live in areas where the average air pollution level exceeds the MPC (1). Major contributors to overall air pollution are made by enterprises of ferrous and nonferrous metallurgy, chemistry and oil-refining, civil engineering, and thermal power stations (8).

We compare here three interrelated data arrays which include the 1992 data for 74 regions and republics of the Russian Federation, and also for Moscow and St. Petersburg (1). The first data array refers to annual industrial releases to the atmosphere expressed in tons/km^2. The second data array concerns the annual releases to the atmosphere per city resident. The third data array gives the annual age-specific mortality from lung cancer at the age of 0-64 per 100,000 persons.

These data demonstrate that the Russian Federation has eight territories with annual air pollution exceeding 0.1 ton per km^2, 18 territories with annual air pollution exceeding 0.35 ton per city resident, and 36 territories in which the number of deaths from lung cancer at the age of 0-64 years exceeded 28 per 100,000 persons a year. In the last group of territories, the individual annual risk of death from lung cancer exceeded 2.8×10^{-4}.

As should be expected, the Chelyabinsk and Lipetsk regions are included in all three groups of territories. The individual annual risk of death from lung cancer due to air pollution with industrial releases of noxious substances for these two regions is almost 3×10^{-4}. The annual atmospheric release per city resident is 0.69 ton for the Lipetsk Region and 0.61 ton for the Chelyabinsk Region.

In less industrially contaminated territories (such as the republics of Dagestan or Karachay-Cherkessia), the mortality from lung cancer at ages 0-64 years is nearly two times lower. The annual atmospheric releases per person were 0.04 ton for Dagestan and 0.12 ton for the Karachay-Cherkessia Republic. The lack of correlation between the risk of death from lung cancer and the annual releases to the atmosphere can be accounted for by differences in released chemicals and in their distributions in the inhaled air. Also one should bear in mind the differences in the dynamics of annual atmospheric releases in the preceding years and the existence of a time delay (latency) in the development of lung cancer.

4.2.2 WATER AND SOIL POLLUTION WITH INDUSTRIAL WASTES

The current level of drinking water supply service is inadequate in almost every region of the Russian Federation. In 1993, the quality of the drinking water supply remained practically at the same level as in 1991 or even deteriorated in many areas as a result of growing economic difficulties and a worsening ecological situation (1). In general, about 50% of the Russian population uses drinking water that does not satisfy the hygenic requirements with respect to a wide range of water quality parameters (1).

The most widespread substances contaminating the surface waters in Russia are still oil products, phenols, easily oxidizable organic substances, metal compounds, nitrite and ammonium nitrogen (8). The underground aquifers used to supply drinking water contain nitrogen, iron, and manganese compounds, sulphates, chlorides, oil products, phenols, strontium, aluminum, and lead. The content of these contaminants ordinarily does not exceed five times the MPC (8). As a rule, the underground sources of drinking water are better protected against technogenic contamination than the surface ones (8).

The situation with the quality of drinking water is particularly unsatisfactory in the Arkhangelsk, Kursk, Tomsk, Yaroslavl, Kaluga, Kaliningrad, Tula, Kurgan and other regions, i.e., in practically all the industrial areas of Russia.

In 1995, the condition of soils involved in economic activity remained unsatisfactory (8). A steady intensification of processes of technogenic contamination of soil with heavy metals, oil, oil products, radionuclides, and other toxic substances has been observed in recent years (8).

Unfortunately, many data necessary for quantitative assessment of the risk of death related to water and soil contamination (such as data on the distribution of toxic contaminants in reservoirs, in the soil, in food chains, diets, etc.) are not available at present. Qualitative assessments, however, show that the level of this risk is much lower than that related to air pollution.

4.2.3 INDOOR AND TRANSPORT-RELATED ACCIDENTS

This section includes all types of accidents that may happen at home or in any other premises: poisonings by medicines, household chemicals, vapors or gases, by other solid or liquid substances, falls, shocks by electric current, burns, injuries by falling objects, fires, etc. As an illustration, in 1992 the individual annual risk of fire for the Russian population was 7×10^{-5}.

Outside the home, in addition to the above-mentioned accidents, people are subjected to many more types of accidental injuries that may happen in city streets, roads, in any kind of transport, drowning, etc. Table 4.1 gives the dynamics of risk of death from all kinds of injury and poisoning for the population of Russia in 1981-1993 (1). These data suggest the following conclusions. First, in the first half of the 1980s, there was a steady decrease of the risk of death from accidental injuries and poisonings. The minimum of 1.02×10^{-3} was recorded in 1987 and was apparently related to the system of state-organized antialcoholic measures actively carried out at that time. Secondly, in subsequent years, especially in 1993, there was a drastic increase of this risk. In 1993, the risk of death from accidents increased more than twofold in comparison with 1987, and exceeded the risk of death from cancer (see Table 2.3).

Analysis of the age dependence of the risk of death from accidental injuries and poisoning has demonstrated its similarity with the age dependence of disease-related risk of death (see Figure 2.1). The initial decrease of the death risk can be attributed to the increase in viability and decrease of vulnerability with age for young age groups. The minimal risk of death from accidental injuries and poisoning is recorded for the 10-14 year group. This risk increases drastically with age, particularly in the 20-24 year group. Recently, however, this risk has also increased in the whole range of economically active ages of males (injuries suffered at work are discussed in Section 5).

The risk of death from accidental injuries and poisoning is highly nonuniform for various Russian territories. According to data for 1992 (1), such risk for the whole population was minimal (less than 8×10^{-4} per person per year) in Dagestan. An individual annual risk ranging from 8.0×10^{-4} to 1.1×10^{-3} was characteristic at that time for the Checheno-Ingush, Kabardino-Balkaria, and Karachay-Cherkessia republics. Maximal individual annual levels of this kind of risk for the whole Russian population (from 2.95×10^{-3} to 3.75×10^{-3}) were recorded in the Altai and Tuva republics. On a large

part of the center and south of European Russia and in the Urals, the individual annual risk of death from accidental injuries and poisoning did not exceed 1.75×10^{-3}. In many regions of Siberia and the Far East, the individual annual risk did not exceed 2.25×10^{-3}. Recall that the average value of this risk for Russia in 1992 was 1.74×10^{-3} per person per year (Table 4.1).

4.2.4 EMERGENCY SITUATIONS OF TECHNOGENIC ORIGIN

These emergency situations, usually involving considerable material damage and loss of human lives, occur as a result of air crashes, railway crashes and accidents, fires, explosions and accidents at gas and oil pipelines, at mines, power stations and other industrial and power plants. In recent years, the spread of technogenic emergency situations has acquired such proportions in Russia that it has led to irreversible ecological damage and has become a threat to the safety of the state and its population (3). So now we have a drastic growth of technogenic risk for the Russian population.

The territories of Russia differ very much in the incidence of occurrence of technogenic emergency situations. A study of the variation of the number of ecological and ecologically significant ES in 1992 and 1993 as compared to the average level for 1989-1993 led to the following conclusions:

1. The number of regions in which there were no ES at all, or their frequency decreased or remained unchanged over that period of time, is very small.
2. On the main part of the Russian territory, the ES frequency in those years increased from 1.5- to 2.5-fold. Table 4.2 gives estimates of the technogenic risk of death for various large territories of Russia and for Russia as a whole according to the 1992 data on ES (2).

Thus, the individual annual technogenic risk of death for various territories of Russia ranges from 0.70×10^{-5} to 1.88×10^{-5} per person per year.

4.3 COMPARISON OF TECHNOGENIC RISKS OF DEATH FOR THE RUSSIAN POPULATION

The overall estimates of risk of death from technogenic environmental factors of different origins for the Russian population in 1992 are presented in Table 4.3.

It should be noted that the maximal number of emergency situations of technogenic origin (such as explosions in mines, fires at oil refinery plants, etc.) was recorded in 1992 (3). However, this particular technogenic factor does not make the principal contribution to the overall technogenic risk of death but holds only third place. The principal contribution to the overall technogenic death risk comes from accidental injuries (road, transport, and indoor accidents) and poisoning. This particular risk of death is very high (up to nearly 4×10^{-3} per person per year), i.e., it constitutes an appreciable fraction of the risk of death from disease for the whole population.

The second largest contributor to the total individual annual technogenic death risk is atmospheric pollution by industrial releases (up to 3×10^{-4}).

4.4 CONCLUSIONS

Accidental injuries (road, transport and indoor accidents) and poisonings make the main contribution to the overall technogenic risk of death for the population of Russia. A drastic increase of mortality from these causes has been recorded in recent years. In 1992, this particular risk of death exceeded the death risk from cancer and reached 1.7×10^{-3} per person per year. The distribution of the individual annual risk of death from accidental injuries and poisonings is highly nonuniform: from 8×10^{-4} for Dagestan to 3.8×10^{-3} for the Altai and Tuva republics. In 1993, the average individual annual risk of death from accidental injuries and poisonings for the population of Russia was as high as 2.27×10^{-3}.

The second largest contribution to the overall technogenic risk of death for the Russian population comes from the heavy atmospheric pollution by toxic industrial releases that occur in many of Russia's territories. The corresponding individual annual risk of death reaches 3×10^{-4}.

Although the number of technogenic emergency situations in Russia is exceptionally high and has been growing steadily over the last few years, this source of hazard from man-made environmental factors holds only third place as a contributor to the overall technogenic risk of death for Russia's population.

Further separate and more thorough consideration should be given to the so-called technogenically induced natural disasters or cataclysms, such as earthquakes or floods. As mentioned in Section 3.5, intensive technogenic activity (building of hydroelectric power plants, ore mining, industrial explosions, etc.) can lead to dangerous natural phenomena; for instance, it can increase the seismic hazard in hitherto low-risk areas.

Comparison of the natural and technogenic risks has revealed that in regions with a maximum technogenic risk the latter exceeds by an order of magnitude the corresponding risk of natural origin. The overall technogenic risk of death for the Russian population makes up an appreciable share of the corresponding risk of death from disease.

As in the case of natural environmental risk of death, there are no sufficient data available in order to estimate quantitatively the technogenic risk of death for different age groups separately. Qualitatively, it certainly is highly dependent on age: it is minimal in the 10-14 year group but is quite high for infants and old-age groups. In contrast to the natural environmental risk, this risk sharply increases in the 15-19, 20-24, 25-29, and 30-34 year groups on account of increased risk of death in road and transport accidents for males. In these age groups (particularly at 20-24 and 25-29 years), the risk of death in road and transport accidents noticeably exceeds the risk of death from disease because there is a pronounced tendency for males of these ages to get involved in road and transport situations with an unjustifiably high level of risk of adverse and fatal aftereffects. This effect of increased mortality of young males in transport accidents has a considerable social significance as it entails a substantial loss of life expectancy for every accident.

Table 4.1: Individual annual risk of death from all injuries and poisonings for the Russian population in 1981-1993 (x 10^{-3}).

Years	Injuries and Poisonings	All Causes
1981	0.166	1.234
1982	0.158	1.190
1983	0.157	1.214
1984	0.162	1.262
1985	0.140	1.226
1986	0.104	1.050
1987	0.102	1.050
1988	0.115	1.050
1989	0.121	1.153
1990	0.136	1.193
1991	0.144	1.198
1992	0.174	1.265
1993	0.227	1.473

Table 4.2: The individual annual risk of death in technogenic emergency situations for all Russia and various Russian territories (x 10^{-5}).

No.	Territories	Risk of Death
1	All Russia	0.90
2	Northwest	0.69
3	Center	0.87
4	Volga Regions	0.80
5	North Caucasus	1.05
6	Urals	1.28
7	West Siberia	0.75
8	East Siberia	1.85
9	Transbaikalia	1.88
10	Far East	1.13

Table 4.3: The technogenic risk of death for the population of Russia in 1992.

No.	Technogenic Factor	Risk of Death
1	Atmospheric Pollution	1.5×10^{-4} - 3.0×10^{-4}
2	Water and Soil Contamination	---
3	Road, transport, and indoor accidents	8.0×10^{-4} - 3.8×10^{-3}
4	Technogenic ES	0.7×10^{-5} - 1.9×10^{-5}
	All Factors	0.7×10^{-5} - 4.1×10^{-3}

5.0: PROFESSIONAL ACTIVITY AS A SOURCE OF DEATH RISK

5.1 INTRODUCTION

The main causes of death related to professional activity are either work accidents or occupational diseases. High-risk jobs can be found in many industries, power engineering, civil engineering, transportation, as well as in non-industrial occupations (firemen, policemen, steeplejacks, rescue workers, etc.).

Industries involving unhealthy or dangerous working conditions are to a large extent concentrated in the northern and eastern territories of Russia. There are a great many people working in highly unhealthy conditions in European Russia too, both in regions with well-developed heavy industry and in those with relatively weak industrial development (1).

The contribution of unhealthy and hazardous work conditions is particularly pronounced in the Urals, the South-Siberian industrial area (Kuzbass-Irkutsk), and on the Pacific coast (1). The risk of accidents with large numbers of victims is very high in the intensive mining areas. In 1993 this risk has showed a tendency to diminish, especially in the oil and gas extracting areas. In the coal mining areas, despite a general decrease of accident frequency, the risk of accidents remains very high, partially due to the growing strike movement (1).

An analysis of occupational risk of death makes it possible to rank the regions of Russia according to the degree of hazard specific to prevalent industries. For instance, the Urals, Perm and Orenburg regions and the Bashkir republic, with their oil-refining and chemical industries, approach in risk level the predominantly metallurgical Sverdlovsk and Chelyabinsk regions (1).

In writing this section, use was made of relevant data on Russia published largely between 1993-1996 (1-7).

5.2 OCCUPATIONAL RISK OF DEATH FOR THE ECONOMICALLY ACTIVE POPULATION OF RUSSIA

In 1991, the annual occupational risk of death for the economically active population in Russia was 9.4×10^{-3} for males and 2.5×10^{-3} for females. In 1993, the individual annual risk of death increased by 10% for males and by 4% for females and was 1.03×10^{-2} and 2.6×10^{-3}, respectively. These are indeed very high death risk levels. The dynamics of the occupational risk of death for some age groups of the economically active population over the period from 1985 to 1993 is shown in Table 5.1 for males and in Table 5.2 for females. It should be said that the years 1985 and 1986 featured the minimal levels of death risk in the last 20 years for both the entire population and for the economically active age groups.

Comparison of the data for 1993 with those for 1985-1986 revealed the following changes. The individual annual occupational risk of death for males increased from 1.1×10^{-2} to 1.6×10^{-2}, i.e., by a factor of 1.45. For the economically active ages this risk increased by a factor of 1.7 (25-29 years), 1.79 (30-34 years), and 1.86 (35-39 years). The individual annual occupational risk of death for

females increased from 1.07 x 10^{-2} to 1.3 x 10^{-2}, i.e., by a factor of 1.2. For the age group of 35-39 years this risk increased by a factor of 1.5. As a whole, the variation of the occupational risk of death in the economically active age groups of females was relatively not large, particularly before 1992.

Based on the above indicated estimates of the occupational risk for the economically active part of the population, one can assert that at present the situation with labor protection, safe working conditions, as well as with preventive measures of any kind against occupational diseases, accidental injuries and poisoning is not only highly inadequate but rather critical (3).

Nowadays, all the conditions for a further steady growth of occupational risk of death exist in Russia. The proportion of people that work in hazardous and unhealthy conditions in industry increases from year to year (e.g., from 17.8% in 1991 to 21.6% in 1993). By the beginning of 1994, in the industrial, engineering, transport, and communication enterprises, the number of workers whose working place did not satisfy the corresponding safety standards and requirements was 4.6 million. In industry more than a third of all those working in dangerous and harmful working conditions were women. A direct consequence of unsatisfactory conditions and insufficient labor protection are occupational diseases and accidents. Starting in 1989, there has been in Russia a steady increase in the number of victims of occupational diseases, accidents, and poisoning. By 1993, the annual risk of occupational disease reached 1.85 x 10^{-4} per worker. Particularly high levels of occupational morbidity have been recorded in coal mining, light industry, automobile, and agricultural engineering. Injuries on the job predominate in agriculture, lumber industry and motor vehicle transport. In 1993, the annual risk of accidental work death in all industries was 1.4 x 10^{-4} per worker.

5.3 OCCUPATIONAL RISK IN DIFFERENT REGIONS OF RUSSIA

The assessment of occupational risk in different regions of Russia was made on the basis of data on accidental deaths on the job in 1990-1992 for all industries (1). Here is the distribution of Russian territories according to the annual risk of death from on-job injuries (per worker) in 1990-1992.

<u>Less than 1 x 10^{-5}</u>:
Five territories, including Tver, Ryazan, and Tambov regions; Chuvash and Mariy-El republics.

<u>From 1 x 10^{-5} to 2.2 x 10^{-5}</u>:
16 territories, including Novgorod, Moscow, Vladimir, Kaliningrad, and Omsk regions.

<u>From 2.2 x 10^{-5} to 4.3 x 10^{-5}</u>:
17 territories, including Leningrad, Pskov, Tula, Bryansk, and other regions; Adygei, Karelia, and other republics.

<u>From 4.3 x 10^{-5} to 8.6 x 10^{-5}</u>:
16 territories, including Tyumen, Irkutsk, Amursk, Orenburg, and other regions.

<u>From 8.6 x 10^{-5} to 1.7 x 10^{-4}</u>:
12 territories, including Perm, Sverdlovsk, Chelyabinsk, Rostov, and other regions; Krasnoyarsk kray; and Kalmykia, Tuva, and other republics

From 1.7×10^{-4} to 2.9×10^{-4}:
3 territories: Kabardino-Balkaria, Komi, and Yakutia republics.

From 2.9×10^{-4} to 5.7×10^{-4}:
3 territories: Checheno-Ingush republic and Kemerovo and Magadan regions.

5.4 CLASSIFICATION OF OCCUPATIONAL SAFETY CONDITIONS

At present the situation with respect to labor protection and work safety conditions in Russia is steadily deteriorating in view of the general economic crisis. Therefore, our classification of occupational safety conditions (Table 5.3) is based on relevant data for highly developed countries of Europe and America (4, 5, 7). In these countries, the individual annual risk of accidental work-related death for such traditionally low-risk industries as textile, food, shoe, paper, printing, or timber industries is less than 1×10^{-4}. These working conditions can be called safe (Grade I).

The next order of work-related death risk, 1×10^{-4} to 1×10^{-3}, covers metallurgy, shipbuilding, construction, coal mining, iron and steel production, pottery, the average level for all industries, and also civil aviation (flight personnel). These work conditions we call relatively safe (Grade II).

The order of risk 1×10^{-3} to 1×10^{-2} corresponds to the occupational conditions in such industries as charcoal carbonization, vulcanization, etc. This range of risk is typical of fishing boat crews, construction workers, jet bomber crews, tractor drivers, etc. We call these working conditions unsafe (Grade III).

Finally, the order of risk 1×10^{-2} and higher involves workers in mustard gas production, test pilots, jet fighter or military helicopter crews, etc. Their working conditions may be called highly unsafe (Grade IV).

5.5 CONCLUSIONS

In the Russian Federation, the situation with working conditions and labor protection is indeed critical. About five million people (more than 17% of those engaged in economic activity) are working under conditions that fail to meet the labor protection standards with respect to concentration of toxic substances in air, noise, vibration, microclimate parameters, and other indices (3). These conditions are primarily produced by low-quality technological processes, high degree of wear of machinery and equipment, low efficiency of protective measures, and insufficient control of labor safety (3). Nevertheless, in 1993, the range of individual annual risk of death from on-the-job injuries over all Russian territories and industries was from about 1×10^{-5} to 6×10^{-4}, with an average of 1.4×10^{-4}, and these values correspond to relatively safe working conditions (Table 5.3).

At the same time, the individual annual risk of death from all causes for people of economically active ages reached a very high level: more than 1×10^{-2} for males and about 3×10^{-3} for females. These values are much higher than the maximal risk of death from work injuries. Obviously, besides purely occupational factors, some other reasons for this hyper-mortality of economically active people must exist. There are strong grounds to assume that the current hyper-mortality is mainly due

to social origin factors rather than to unsafe working conditions. The present-day socio-economic crisis in the Russian Federation introduced basic alterations in the structure of population mortality. In the forefront now are the risks of death from various causes of social origin: tuberculosis, mental disorders, alcoholism, drug addiction, suicides, and homicides.

Table 5.1. The individual annual occupational risk of death for males of economically active age in Russia (x 10^{-3}).

Age group, years	1985-1986	1990	1991	1992	1993
20-24	2.5	2.6	2.7	3.2	3.8
25-29	3.0	3.3	3.5	4.2	5.1
30-34	3.9	4.3	4.5	5.5	7.0
35-39	5.0	5.6	5.9	7.1	9.3
40-44	8.1	7.6	8.0	9.8	13.3
45-49	10.7	11.7	11.6	13.5	17.8
50-54	16.2	16.1	16.5	19.4	25.3
55-59	22.7	23.4	23.3	25.3	31.3
Total	11.0	11.6	11.9	13.1	16.1

Table 5.2. The individual annual occupational risk of death for females of economically active age in Russia (x 10^{-3}).

Age group, years	1985-1986	1990	1991	1992	1993
20 - 24	0.6	0.7	0.7	0.8	1.0
25 - 29	0.8	0.8	0.9	1.0	1.2
30 - 34	1.1	1.1	1.1	1.3	1.6
35 - 39	1.6	1.6	1.6	1.9	2.4
40 - 44	2.6	2.4	2.5	2.8	3.7
45 - 49	3.6	3.8	3.8	4.2	5.4
50 - 54	5.9	5.4	5.5	6.1	7.9
55 - 59	8.8	8.6	8.6	9.1	10.9
Total	10.7	10.9	11.0	11.4	13.0

Table 5.3. Classification of working conditions.

Grade	Working Conditions	Range of Individual Annual Risk
I	Safe	$< 1 \times 10^{-4}$
II	Relatively safe	$1 \times 10^{-4} - 1 \times 10^{-3}$
III	Unsafe	$1 \times 10^{-3} - 1 \times 10^{-2}$
IV	Highly unsafe	$>1 \times 10^{-2}$

6.0: NONPROFESSIONAL ACTIVITY AS A SOURCE OF DEATH RISK

6.1 INTRODUCTION

In contrast to certain involuntary risk to which particular groups or the entire population may be exposed (e.g., risk of adverse effects of atmospheric pollution by industrial releases) and which is generally controlled by special state or governmental agencies, there are certain kinds of activities which involve voluntary risk. These include amateur sports, tourism, recreational hunting and fishing, and so on. Here every person uses his or her own judgment to assess risk. There are individuals inclined to engage themselves in very high-risk activities, in which the voluntary risk of death exceeds 1,000-fold any involuntary risk.

Unfortunately, there are not sufficient amounts of data available on the risk of death in nonprofessional activities for the present-day Russia. Therefore, we have used risk estimates for various amateur sports published earlier (1-3).

6.2 RISK OF DEATH FOR AMATEUR SPORTS

Rough estimates of the risk of fatal outcome for some kinds of amateur sport are listed in Table 6.1. Because of the specific nature of these pastimes, the risk here is referred to one hour of practicing sports and not to one year as in the preceding sections.

As shown by comparison of the risk of death in different amateur sports with the individual risk of death from disease for the population (about 1×10^{-6} per hour), only the first four sports from Table 6.1 can be considered safe. In other sports, the risk of death from accidents per hour exceeds, sometimes considerably, the individual risk of death from disease for the population. These sports may be regarded as unsafe or highly unsafe. The high levels of death risk in these sports are generally compensated for by the small number of persons involved and a relative reduction of the maximum risk time (with the corresponding increase of the time of training in less perilous conditions). For instance, in the case of horse racing, for which the death risk may be as high as 1×10^{-4} per hour, the time of the actual performance would not usually exceed 100 hours a year.

6.3 CLASSIFICATION OF SAFETY CONDITIONS IN AMATEUR SPORTS

By analogy with the classification of occupational safety conditions given in Section 5, especially 5.4, we propose a similar classification for nonprofessional sport (Table 6.2). As distinct from the former case, conditions II and III are put together because of shortage of statistical data.

The data given in Table 6.2 have been calculated on the assumption that the total time of sport performance (without training time) is no more than 200 hours a year. If that is so, then it is only for the highly unsafe sports that the risk of death exceeds the individual annual risk of death from disease (about 10^{-2}).

6.4 CONCLUSIONS

This chapter considered the fully voluntary risk of death involved in amateur sports. The shortage of published data on this subject prevented us from presenting a sufficiently complete classification of safety conditions in amateur sports. However, analysis of levels of risk related to this type of activity shows the ranges of risk an individual is prepared to run in a modern society in order to achieve a chosen aim.

Table 6.1. Individual risk of death for amateur sports.

No	Sport	Risk of Death (per hour)
1	Cycling	3.0×10^{-7}
2	Hunting	7.0×10^{-7}
3	Boxing	4.5×10^{-7}
4	Skiing	7.1×10^{-7}
5	Motor-cycling	6.7×10^{-6}
6	Boat racing	1.0×10^{-5}
7	High-altitude climbing	4.0×10^{-5}
8	Mountaineering	2.7×10^{-5}
9	Horse racing	1.0×10^{-4}
10	Steeple-chasing	5.0×10^{-4}

Table 6.2. Classification of safety conditions in nonprofessional sport.

Grade	Conditions of activity	Range of individual annual risk of death	Sport
I	Safe	$< 1 \times 10^{-4}$	Cycling, boxing, skiing, hunting
II - III	Relatively safe	1×10^{-4} - 1×10^{-2}	Motor-cycling, boat-racing, high-altitude climbing, mountaineering,
IV	Highly unsafe	$> 1 \times 10^{-2}$	Horse racing, car racing, steeple-chasing

7.0: SOCIAL ENVIRONMENT AS A SOURCE OF DEATH RISK

7.1 INTRODUCTION

The social environment is known to be a major factor in the life of contemporary man, one which has a marked effect on his health and life. The principal causes of death as a result of a direct or indirect influence of the social environment include suicide, various crimes, alcoholism, drug addiction, and a variety of other society-related phenomena. Social destabilization has a particularly pronounced effect during economic crises. The crisis that is currently under way in the Russian Federation is not only of an economic but also of a social-psychological nature, and this is clearly manifested in the increasingly frustrated state of the Russian population.

The onset of so-called "perestroika" brought about among the Russian public a wave of emotional upsurge and enthusiasm, and hopes for a more decent life, which created an atmosphere of general mental well-being. This was manifested in a significant decrease in the number of homicides, robberies, rapes, and other crimes in 1986-1987. Compared to 1985, mortality due to homicides in 1986-1987 decreased by nearly 25%, and that due to suicides by about 27%. An undoubtedly considerably favorable effect was also exerted by the anti-alcoholic decree of 1985, which appreciably limited the production and trade of alcoholic drinks (1).

However, within some four to five years after the beginning of perestroika, these high expectations proved futile and were gradually replaced with a fairly general and intense sense of disillusionment. The growth of mental distress resulted not only in a drastic increase of mortality, but also in social anomalies, such as suicides or homicides (1). The number of dissatisfied people in Russia has continued to grow at a fairly high rate ever since.

The most likely mechanism that relates dissatisfaction with life and mental frustration with increased mortality seems to be excessive stress. It is known to have a severe negative effect on the cardiovascular and immune systems. As a result, there is an increased risk of hypertension and other heart and brain disturbances, mental disorders, depressions, etc. (1)

In writing this section, use was made of data published mainly in 1994-1995 (1-7).

7.2 RISK OF DEATH FROM SUICIDES AND SELF-INFLICTED INJURIES

Many investigators consider the suicide rate to be a highly sensitive indicator of social-psychological disharmony (1). The dynamics of suicide reflects changes in the social environment that occur during economic and political perturbations and crises.

According to mortality due to suicides and self-inflicted injuries (calculated per 100,000 individuals), all countries have been divided into four groups: those of very low (less than 5 cases), low (5 to 9 cases), moderate (10 to 19 cases), and high (20 and more cases) mortality levels (1). Russia, which in 1990 had rather high indices (43.2 for males and 11.1 for females), belongs to the group of high-level mortality from suicides and self inflicted injuries (1, 2). It should be noted that official statistics on suicide-related mortality have practically become available only after 1990.

In the period from 1990 to 1993, according to official data, the mortality from suicides and self-inflicted injuries has increased significantly in Russia, especially for men (see Table 7.1) (2). Note the high level of risk of death from suicides and self-inflicted injuries for males and a drastic increase of this risk in 1993 (by 51%). Risk of death for males in 1990 was four times that for females. By 1993 this ratio increased to 5.1.

The age-specific risk of death from suicides and self-inflicted injuries is shown in Table 7.2 (2). From 1990 to 1993, there was a sharp growth (by 70%) of the suicide-related death risk in the 50-59 year group. For the age groups of 40-49, 50-59, and 70 and more, the individual annual risk of death from suicides exceeded 1×10^{-3}. This is a very high death risk, which testifies to a high degree of dissatisfaction with life in present-day social and economic conditions in Russia and to a dramatic mental distress.

For various female age groups, changes in suicide-related death risk were less pronounced (Table 7.3) (2). In the worst case (25-29 years), the risk of death from suicide increased from 1990 to 1993 by 43%. In this age group, the risk of death from suicide is 7.5 times lower for females than for males. In the adjacent age group (30-39 years), this ratio is 7.9. The highest risk of death from suicide for females is for the age of 70 and more, about 3×10^{-4}.

When examining the distribution of the individual annual risk of death from suicides and self-inflicted injuries over the territories of Russia, we used data on age-specific mortality rates referring to the entire population in 1992 (3). (Recall that this particular risk for 1992 was 3.1×10^{-4} (2).) The distribution of the individual annual risk of death from suicides and self-inflicted injuries over the Russian territories in 1992 was as follows.

<u>Below 0.5×10^{-4}: four territories</u>:
(Dagestan, Karachay-Cherkessia, North Ossetia, and Checheno-Ingush republics)

<u>From 0.5×10^{-4} to 1.5×10^{-4}: two territories</u>:
(Kabardino-Balkaria republic and the Voronezh region)

<u>From 1.5×10^{-4} to 2.45×10^{-4}: 11 territories</u>:
(Stavropol territory; Adygei republic; Rostov, Belgorod, Bryansk, Orel, and other regions)

<u>From 2.45×10^{-4} to 3.3×10^{-4}: 19 territories.</u>

<u>From 3.3×10^{-4} to 4.9×10^{-4}: 13 territories</u>.

<u>From 4.9×10^{-4} to 5.8×10^{-4}: eight territories</u>:
(Arkhangelsk and Kirov regions; Karelia, Mariy-El, Bashkiria, Udmurtia, Altai, and Buryatia republics)

So, the maximum annual individual risk of death from suicides and self-inflicted injuries in Russia reached 5.8×10^{-4} by 1992.

7.3 RISK OF DEATH FROM CRIMES

The dynamics of risk of death from crimes in Russia in the period from 1990 to 1993 are shown in Table 7.4 (2).

There is a sharp growth of individual annual risk of death from crimes: from 1990 to 1993 it grew more than two-fold for the entire population and exceeded 3×10^{-4}. We can observe a growing similarity between the risks of death from crimes and from suicides. The individual annual risk of death from crimes for males in 1993 was nearly 5×10^{-4}. For females it increased about two-fold to become nearly 1.4×10^{-4}.

Among the territories with a high level of criminality, one can mention (in increasing order) the Kurgan, Pskov, Leningrad, Tomsk, and Sakhalin regions, the Primorski territory, and the Tuva republic (1). The Leningrad and Omsk regions had an especially high rate of crime incidence growth (by about 200% from 1990 to 1992) (3).

7.4 RISK OF DEATH RELATED TO ALCOHOL CONSUMPTION

In the last few years, against the background of increased alcohol intake and the related aggravation of the problem of alcoholism, there has been a marked rise in mortality due to alcohol poisoning (4), as well as in mortality from various causes associated with alcohol intake. The same applies to the economically active part of the population (see Table 7.5). Table 7.5 includes causes of death related to alcohol intake, such as alcohol poisoning, chronic alcoholism, alcoholic psychosis, or alcoholic liver cirrhosis (2). There is a marked increase in risk of death from these causes by 1993, particularly for men of economically active ages. For the latter category, in 1993 the individual annual risk of death from alcohol-related causes reached 8.1×10^{-4}. One can see a very sharp growth of risk of death from alcoholism in females, particularly in the economically active ages.

The dynamics of the alcohol-related risk of death for the whole Russian population over a prolonged period of time (from 1984 to 1993) is shown in Figure 7.1 (4). The initial drop in 1984-1988 was due to extensive anti-alcoholic measures taken by the authorities at that time. After the campaign had been discontinued, the risk of death started to grow. A particularly sharp increase took place in 1992-1993. Within the period from 1988 to 1993, the alcohol-related risk of death for the whole population increased by a factor of 4.1. A similar dynamic is recorded, in particular, for the risk of death from accidental alcohol poisoning (Figure 7.2) (4).

In 1992, the annual alcohol consumption in Russia returned to the initial level (1984) of 14.1 liters of absolute alcohol per individual. By 1993, the individual annual consumption of alcohol grew by an additional liter. Incidentally, according to the standards of the World Health Organization (WHO), the situation with alcohol in a country is considered dangerous when its consumption reaches an annual level of eight liters of absolute alcohol per person. For the particular conditions of Russia, each liter of alcohol consumed per person per year resulted in 132,000 additional deaths a year in addition to natural mortality (4).

7.5 RISK OF DEATH FOR INFANTS

The risk of death for infants below one year of age is a very sensitive indication of the social conditions in a country. Over the period from 1960 to 1993, the death risk for infants in Russia underwent serious alterations (2). These alterations, however, were different for city and country residents (see Table 7.6). The changes in the infant mortality in Russia show two distinct features: (1) a drastic (greater than two-fold) reduction in the infant mortality risk from 1960 to 1990, and (2) a pronounced increase of the same risk after 1990. In 1993, the annual risk of infant death was about 2 x 10^{-2} per newborn. This level of infant mortality is characteristic of many countries of medium economic development and low per capita income (5). In highly developed countries, this level is three times lower on the average. In Japan, it is five times lower (5, 6).

The results of an analysis of the principal causes of death contributing to the risk of infant death are summarized in Table 7.7 (2). It can be seen that the main contributions to the risk of infant death come from perinatal disorders and congenital anomalies. Next come respiratory, infectious, and parasitic diseases. A noticeable share of this risk belongs to accidents, poisonings, and injuries (about 5% in 1993).

Over most of the Russian territory the annual risk of infant death does not exceed 2.2 x 10^{-2} per newborn, according to data for 1993 (3). However, there are regions in which this risk is higher. For example, in the Ulyanov region, this risk ranges from 2.2 to 2.5 x 10^{-2} per newborn. A very high annual risk of infant death (from 3.0 to 3.23 x 10^{-2} per newborn) was recorded in Checheno-Ingush and Tuva republics, as well as in the Kemerovo region, which is indicative of very unsatisfactory social and economic conditions in these territories of Russia.

7.6 CONCLUSIONS

The main contribution to the total individual annual risk of death from social causes for the whole population was made, according to the data for 1993, by suicides and self-inflicted injuries (3.81 x 10^{-4}). Next came the risk associated with alcohol consumption (3.59 x 10^{-4}). Finally, the third place was held by the risk of death from crimes (3.06 x 10^{-4}) (7).

For males the leading risk of death was from suicides (6.62 x 10^{-4}). Second place was held by alcohol-related causes (5.93 x 10^{-4}), and third by crime-related death risk (4.95 x 10^{-4}). The levels of risk related to social causes for males are very high. For females, first came alcohol-related causes (1.47 x 10^{-4}) per person per year). Second and third places were held by the risk of death from crimes (1.35 x 10^{-4}) and from suicides (1.29 x 10^{-4}), respectively (7).

Analysis of the time course of suicide-caused death for males of various age groups suggests the following conclusions. (1) In the period from 1990 to 1993, there was a very sharp increase (by 70%) of the risk of death in the 50-59 year age group. (2) For some age groups (from 40 to 70 years and older), the individual annual risk of death from suicide in the same period of time reached a very high level, exceeding 1 x 10^{-3} (7).

Unfortunately, there are no published data on the age distributions of alcohol-related and crime-

related risks of death.

Examination of the distribution of the individual annual risk of death from suicides and self-inflicted injuries over various territories of Russia revealed that its maximum level was 5.8 x 10^{-4} (data for 1992) (7). Infant mortality, which is a very sensitive indicator of social and economic conditions, is very high in Russia compared to the advanced countries of the world.

In conclusion, a careful analysis of the data pertaining to the social environment in Russia as a source of risk of death definitely demonstrates that the prevailing mental and psychological distress and dissatisfaction in the present-day Russia constitute a genuine threat to the national safety of this country.

Table 7.1 Variation of individual annual risk of death from suicides and self-inflicted injuries (x 10^{-4}).

Years	Whole population	Males	Females
1990	2.64	4.39	1.11
1991	2.65	4.45	1.07
1992	3.10	5.32	1.16
1993	3.81	6.62	1.29

Table 7.2. Individual annual risk of death from suicides in various age groups of men (x 10^{-4}).

Age group, years	Risk of Death			
	1990	**1991**	**1992**	**1993**
All ages	4.39	4.45	5.32	6.62
Below 20	0.89	0.93	0.97	0.92
20 - 24	3.40	3.52	4.26	5.22
25 -29	4.96	5.11	5.97	7.35
30 - 39	6.14	6.34	7.55	9.28
40 - 49	6.96	6.64	8.06	10.38
50 - 59	6.97	7.10	9.20	11.84
60 - 69	6.33	6.41	7.47	8.77
70 and over	9.61	8.80	8.25	10.36

Table 7.3. Individual annual risk of death from suicides for females of different ages (x 10^{-4}).

Age group, years	Risk of Death			
	1990	1991 1992 1993		
All ages	1.11	1.07	1.16	1.29
Below 20	0.23	0.24	0.26	0.23
20 -24	0.69	0.67	0.75	0.81
25 - 29	0.68	0.73	0.78	0.97
30 - 39	0.86	0.84	0.97	1.18
40 -49	1.25	1.21	1.42	1.57
50 -59	1.61	1.55	1.73	1.89
60 -69	2.01	1.86	1.92	2.07
70 and over	3.07	2.88	2.84	2.94

Table 7.4. Dynamics of individual annual risk of death from crimes (x 10^{-4}).

Year Whole	Risk of Death from Crimes		
	Population	Males	Females
1990	1.43	2.32	0.65
1991	1.52	2.49	0.67
1992	2.28	3.76	0.99
1993	3.06	4.95	1.35

Table 7.5. Dynamics of individual annual risk of death related to alcohol consumption (x 10^{-4}).

Population	Risk of Death			
	1990	1991	1992	1993
1. Whole population	1.23	1.26	1.95	3.59
1a. Economically active	1.76	1.82	2.85	5.06
2. Males	2.09	2.16	3.35	5.93
2a. Economically active males	2.91	3.02	4.69	8.10
3. Females	0.47	0.47	0.73	1.47
3a. Economically active females	0.52	0.54	0.87	1.76

Table 7.6. Dynamics of annual risk of infant death in Russia in 1960-1993.

Years	Risk of Death (x 10^{-2} per newborn)		
	Entire population	**City residents**	**Country residents**
1960	3.66	3.49	3.81
1965	2.66	2.64	2.67
1970	2.30	2.21	2.45
1975	2.37	2.25	2.62
1980	2.21	2.12	2.40
1985	2.07	1.98	2.28
1986	1.93	1.88	2.04
1987	1.94	1.88	2.10
1988	1.89	1.82	2.04
1989	1.78	1.73	1.90
1990	1.74	1.70	1.83
1991	1.78	1.72	1.91
1992	1.80	1.76	1.91
1993	1.99	1.92	2.14

Table 7.7. Principal causes of infant mortality in Russia in 1990-1993.

Principal Causes of Death	**Annual Risk of Death** (x 10^{-2} per newborn)			
	1990	**1991**	**1992**	**1993**
Perinatal disorders	0.801	0.798	0.805	0.880
Congenital anomalies	0.370	0.388	0.386	0.407
Respiratory diseases	0.247	0.271	0.266	0.309
Infectious and parasitic diseases	0.134	0.124	0.117	0.142
Accidents, poisonings, and injuries	0.071	0.078	0.085	0.098
All causes	1.740	1.782	1.805	1.988

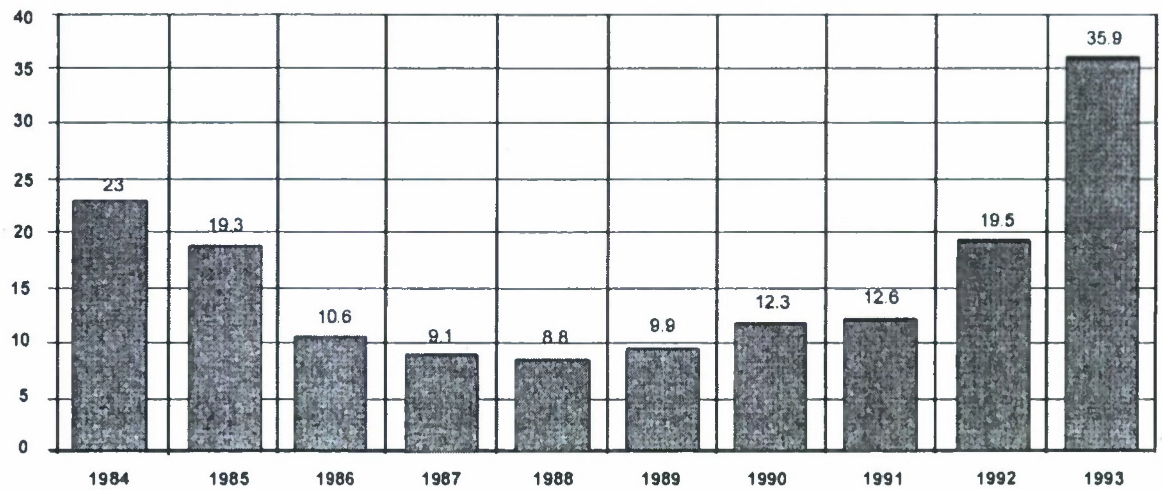

Figure 7.1. Alcohol-related mortality for the Russian population (per 100,000 individuals).
Note: The anti-alcoholic decree came into force on 1 July, 1985.

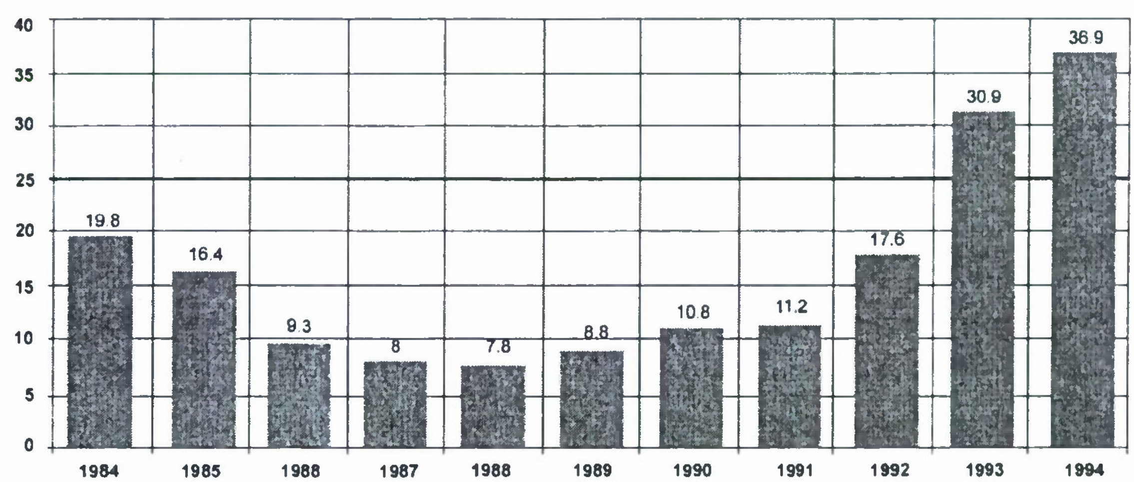

Figure 7.2. Mortality due to accidental alcohol poisoning for the population of Russia (per 100,000 individuals).

8.0: LIFE EXPECTANCY FOR THE POPULATION OF RUSSIA

8.1 INTRODUCTION

In accordance with WHO recommendations, life expectancy at birth is regarded as a most important integral indicator of the health status and quality of life in any region. Ultimately, life expectancy at birth characterizes the safety of living conditions for the population of a given country. The data at our disposal show that the expectation of life is a sensitive enough indicator of population safety.

Life expectancy at birth in Russia was at its maximum - 65.0 years for men and 74.6 years for women - in 1987 and has been steadily decreasing since then. At the same time, in prosperous European countries, life expectancy for men exceeds 70 years and continues to grow. In 1993, the drop in life expectancy in Russia could be called catastrophic: within a year life expectancy decreased by more than three years for men (in the absence of declared wars or natural cataclysms) and by nearly two years for women (1, 2). From 1987 (the year of maximum life expectancy) to 1994, life expectancy was reduced by 7.6 and 3.6 years for men and women, respectively. In 1993, for the first time in recent decades, the life expectancy for men dropped below 60 years. On the other hand, the ever increasing discrepancy in life expectancy for men and women reached 13 years by 1993 and 13.7 by 1994. Such a large and steadily increasing gap is evidence of a considerable social distress (1).

In this section, in addition to life expectancy at birth in Russia and its territories, we also examine, on the basis of published data, the expectancy of remainder of life and the structure of the population working capacity loss (1-5).

8.2 LIFE EXPECTANCY AT BIRTH FOR THE GENERAL PUBLIC

In 1994, the steadily decreasing life expectancy at birth came to very low levels: 57.4 years for men and 71 years for women (64.1 years for both sexes). There was an appreciable difference in life expectancy at birth, not only between males and females, but also between urban and rural residents (Table 8.1) (2).

The situation with male rural residents has been particularly distressing. Up to the middle 1980s, the gap between life expectancies at birth for male urban and rural residents was more than three years. In recent years, this gap has decreased considerably (to 1.4 year in 1993 and 0.8 year in 1994) as a result of the growing mortality rate in the cities.

It should be admitted that the overall decrease in life expectancy at birth in Russia over the period beginning in 1993 (Figure 8.1) has been enormous. It resulted in a further increase of the lag of Russia behind most advanced countries of the world with respect to this parameter (2). This is illustrated by Table 8.2, which gives life expectancies at birth in various countries (3), with India and Japan holding last (59 years) and first (79 years) place, respectively. For years a major effect on changes of life expectancy at birth in Russia has been exerted by the following two classes of causes of death: (1) accidents, poisonings, and injuries (hereafter, for brevity, referred to as "accidents") and (2) cardiovascular diseases (2).

In 1993-1994, an unexpectedly large contribution to male mortality was made by cardiovascular

diseases. A similar trend was shown by females, for which cardiovascular diseases were always the most important factor of mortality (2).

The highly unfavorable structure of death causes for men and its unfavorable dynamics have led to a discrepancy in life expectancy between men and women which probably is the largest in the world (2). This discrepancy is still increasing: it exceeded 13 years in 1993 and 13.7 years in 1994. As follows from Table 8.4, this gap is more than 60% due to the increased mortality of men from cardiovascular diseases and especially from accidents. In contrast to previous years, in 1993-1994 an appreciable reduction of life expectancy for both men and women occurred in almost all age groups (Table 8.5) (2). For males in this period, an increased negative influence on life expectancy came from a growing mortality at ages older than 45. In previous years, a greater relative effect was exerted by mortality at younger working ages (2).

Information on changes of life expectancy at birth in Russia in 1991-1994 in relation to age groups and principal causes of death is summarized in Table 8.6 for men and Table 8.7 for women (2).

The expectation of life at birth in different industrial areas of the Russian Federation is given in Table 8.8 (2). At the end of the 1980s, an increase in life expectancy was observed in some areas of the European North and Siberia, which was related to intensive anti-alcoholic measures undertaken by the state. Upon cessation of this struggle against alcohol, a subsequent reduction of life expectancy was accompanied by an increase in interregional differences. Life expectancy underwent a more rapid reduction in northern and eastern territories than in the south-west of Russia.

In 1993, a very low life expectancy - 55 to 57 years for men and 69 to 71 years for women - was recorded in many regions of Russia (Magadan, Kamchatka, the Amur and Chita regions, the Khabarovsk and Krasnoyarsk territories in Eastern Siberia and in the Far East, the Tomsk region in Western Siberia, Udmurtia in the Urals, the Arkhangelsk region and the Komi republic in north European Russia, and the Novgorod, Pskov, and Tver regions in the northwest). The minima for life expectancies were recorded in Tuva: 52.3 years for men and 64.3 years for women. A relatively better situation was present in many territories of the southeast of European Russia: the North Caucasus republics, the Stavropol territory, the Volgograd, Voronezh, and Belgorod regions, and Mordovia. There life expectancy was 61-64 years for men and 72-74 years for women.

8.3 EXPECTANCY OF REMAINDER OF LIFE FOR THE GENERAL PUBLIC

The WHO recommends that, along with life expectancy at birth, the expectation of remaining life at different ages should also be studied in the framework of health-demographic monitoring. A picture of the distribution of remaining life for the whole population over the Russian territories is given in reference 1 for the ages of 1, 15, 45, and 65 years.

Here is the distribution of expectancy of forthcoming life at the age of 1 year over the Russian territories:

More than 71 years: Dagestan republic.

69.8 - 71 years:
Karachay-Cherkessia and Checheno-Ingush republics.

68.4 - 69.8 years:
Twelve regions: Kabardino-Balkaria, North Ossetia, Stavropol territories, Volgograd, Voronezh, Belgorod, Penza, Omsk, and Ulyanovsk regions; Tatarstan, Chuvashia, and Mordovia.

66.9 - 68.4 years:
31 regions of the center and southern areas of European Russia and two regions of Siberia.

65 - 66.9 years:
Ten regions of European Russia and 11 regions of Siberia.

64 - 65 years:
Six regions of Siberia.

60.7 - 64 years:
Tuva republic.

Next we consider the distribution of expectancy of remaining life at the age of 65 years.

More than 15 years: Dagestan republic.

14.6 - 15 years:
Three regions: Karachay-Cherkessia, Checheno-Ingush, and Tatarstan republics.

14.1 - 14.6 years:
15 regions of the European part of Russia.

13.5 - 14.6 years:
27 regions of European Russia and seven regions of Siberia.

12.8 - 13.5 years:
Nine regions of European Russia and seven regions of Siberia.

11.5 - 12.8 years:
2 regions of European Russia (Karelia and Komi republics) and three regions of Siberia (Yakutia, Khabarovsk territory, and Sakhalin).

10.6 - 11.5 years:
Two regions of Siberia (Kamchatka and Magadan regions).

8.4 STRUCTURE OF LOSS OF WORK CAPACITY

An analysis of the structure of loss of work capacity in the Russian population reveals a system of priorities somewhat different from the generally recognized triad of cardiovascular diseases, malignant tumors, and injuries (1). It turned out that in 1993 practically half of the working capacity loss in the population was due to mortality caused by injuries and poisonings (Table 8.9)

Working capacity loss due to cardiovascular diseases was lower than that due to injuries by nearly 4.5 times. This is explained by the fact that whereas each year injuries and poisonings have been and still are responsible for 70% fewer deaths each year than cardiovascular diseases, the average age of those who have died from injuries (44 years) is almost 30 years lower than that of victims of cardiovascular diseases. The third place is held by perinatal diseases, which are responsible for most infant deaths (see Section 7.0). As infant death means absolute loss of life expectancy, this explains the high rank of perinatal diseases (1).

In 1992, the levels of working capacity loss per 1000 persons due to premature death from any cause differed considerably from territory to territory in Russia. The maximum loss was 30.1 years (Tuva republic) and the minimum loss was 11.5 years (Dagestan republic), showing about a three-fold difference (1).

Comparison of the overall working capacity losses in 1992 and 1989 reveals the following features. In all territories of Russia these losses increased, with the exception of North Caucasus, where they diminished. The largest increase in losses was not shown by the territories such as Siberia or the Far East, where the situation has always been highly unfavorable, but by a number of other areas. These included the territories which in 1992 had a minimal working capacity loss (Orenburg, Saratov, Kirov, Voronezh, and Orel regions and Chuvashia).

There are also noticeable differences in the structure of working capacity loss between the male and female populations of Russia (Table 8.10).

Working capacity loss as a result of injury ranks first both for men and women. However, these particular losses constitute about 58% of the total loss in the male population and only 34% in the female population (47.1% for the whole population, as shown in Table 8.9). Cardiovascular diseases are responsible for about 11% of working capacity loss in the male and female populations of Russia, but they rank second for men and only fourth for women. Also noteworthy is a gap between losses due to injuries and the next largest class of causes of death: for males, the loss from injuries was more than five times that from cardiovascular diseases, and for females, the loss from malignant tumors were nearly three times lower than that from injuries (1).

Analysis of working capacity loss by separate causes of death has shown that the causes of death responsible for maximal losses of working capacity of the Russian population in 1993 were transport injuries, homicides, and suicides (Table 8.11). The capacity loss from each of these causes exceeded that from all classes of tumors.

Working capacity loss due to homicides and suicides taken together were greater than the loss due to

all cardiovascular plus infectious diseases. These data partially account for the drastic reduction of life duration in Russia in the last few years. Indeed, mortality due to malignant tumors is generally specific to older ages and does not affect too much estimation of remaining life expectancy. In contrast, deaths from injuries and poisonings are recorded mainly at economically active ages. This is particularly true for men. Here loss of remaining life is quite considerable. The data presented here demonstrate the presence of highly unfavorable tendencies regarding social safety of the public in Russia (1).

Examination of the dynamics of overall working capacity loss in the Russian population in the period from 1981 to 1993 suggests the following conclusions. In the first half of the 1980s, the working capacity loss diminished from 18.5 person-years of working activity per 1,000 persons in 1981 to 16.2 person-years per 1,000 persons in 1985. Beginning with 1985, the rate of loss reduction grew appreciably, and a minimum working capacity loss of 11.5 person-years per 1,000 persons was achieved in 1987. After 1987 this tendency underwent a reversal. As a result, by 1993 the working capacity loss reached 19.5 person-years of working activity per 1,000 persons.

The recorded rise of total working capacity loss was to a large degree accounted for by the grown number of accidental injuries. Working capacity loss increased from year to year, but particularly so in 1993: by 2.7 person-years per 1,000 men and 0.85 person-years per 1,000 women. The results of a more detailed examination of the dynamics of variation of working capacity loss due to some causes of death belonging to the class of injuries and poisonings are summarized in table 8.12 (1). These data demonstrate a dramatic increase of working capacity loss from year to year due to homicides. In 1993, homicides made the highest contribution to the working capacity loss of the Russian population, even though not all of them were recorded as such (1). Whereas from 1990 to 1991 the loss due to this cause of death increased by 0.10 person-years per 1,000 males and by 0.02 per 1,000 females, from 1991 to 1992 this increment grew sixfold for males and sevenfold for females, being respectively 0.64 and 0.14 person-years per 1,000 individuals. Within the period from 1992 to 1993, the working capacity loss due to homicide increased respectively by 0.55 and 0.17 person-years per 1000 persons. By 1993 it reached 2.61 person-years per 1,000 men and 0.69 person-years per 1,000 women.

Similar acceleration of the rate of growth of working capacity loss was observed in the case of suicides. In 1990-1991, these losses increased by 0.06 and 0.002 person-years per 1000 man and women, respectively. In 1991-1992, the increment was 0.33 and 0.042 person-years, and in 1992-1993, it was 0.54 and 0.068 person-years, respectively. In 1993, the loss due to suicides reached 2.71 person-years per 1,000 men and 0.49 person-years per 1,000 women.

A similar pattern is observed for all alcoholism-related causes of death. The social safety of the Russian population is seriously threatened: first, by the increase in alcoholism-related working capacity loss; second, by the skyrocketing rates of working capacity loss due to social causes; and, third, by the rapidly growing rates of working capacity loss in women due to "alcoholic" mortality, which exceed these rates in men. Indeed, whereas in 1993 the working capacity loss from accidental alcoholic poisoning in men increased 1.6-fold, for women it increased twofold. The losses related to chronic alcoholism in the same year grew 2.5-fold for men and 3.3-fold for women (1).

8.5 CONCLUSIONS

An attempt was made in this chapter to examine the main integral parameters (the life expectancies and the working capacity loss) that characterize the living conditions of the Russian population from the viewpoint of safety.

The above analysis reveals that the health status of the Russian population in 1993 has been extremely unsatisfactory. The dangerous rates of growth of risk of death from purely social reasons brought about a drastic decrease in life expectancy. This is mainly related to death due to accidents, poisonings, and violence, which is an indication of a deep social distress (1). Particularly alarming seems to be the growing incidence of all kinds of injuries in Russia. There is an unprecedented rise in female death from causes that have hitherto been considered purely masculine - homicide and alcoholic intoxication. The growing loss of life due to suicide also testifies to serious social frustration. The criminogenic situation in the present-day Russia is well illustrated by the fact that in 1993 homicides took more lives than any other cause of death.

Table 8.1. Life expectancy at birth for the whole urban and rural populations of Russia (years).

Whole Population

Year	Both sexes	Males	Females
1987	70.2	65.0	74.6
1988	69.9	64.8	74.4
1989	69.6	64.2	74.5
1990	69.2	63.8	74.2
1991	69.0	63.5	74.3
1992	67.9	62.0	73.8
1993	65.1	58.9	71.9
1994	64.1	57.4	71.0

Urban Residents

Year	Both sexes	Males	Females
1987	70.4	65.4	74.5
1988	70.1	65.4	74.2
1989	69.9	64.8	74.5
1990	69.6	64.4	74.4
1991	69.4	64.1	74.3
1992	68.2	62.5	73.8
1993	65.4	59.3	72.0
1994	64.3	57.7	71.0

Rural Residents

Year	Both sexes	Males	Females
1987	69.1	63.2	74.5
1988	68.7	62.7	74.4
1989	68.5	62.6	74.2
1990	67.9	62.0	73.9
1991	67.7	61.7	73.9
1992	66.9	60.7	73.5
1993	64.3	57.9	71.5
1994	63.4	56.9	70.9

Table 8.2. Life expectancy at birth in some countries of the world (years).

Country, Years Studied	Whole Population	Men	Women
Russia, 1993	65	59	72
Australia, 1990	77	74	80
Austria, 1990	76	73	79
Belgium, 1984	74	71	78
Bulgaria, 1989-1991	71	68	75
Great Britain, 1985-1987	75	72	78
Hungary, 1990	70	65	74
Germany, 1990	75	72	79
Denmark, 1989-1990	75	72	78
India, 1989	59	58	59
Canada, 1985-1987	76	73	80
China, 1985-1990	69	68	71
Netherlands, 1991	77	74	80
Norway, 1990	77	73	80
Poland, 1991	71	66	75
Romania, 1988-1989	69	67	73
USA, 1990	75	72	79
Finland, 1989	75	71	79
France, 1990	77	73	81
Switzerland, 1990-1991	78	74	81
Sweden, 1990	78	75	80
Japan, 1990	79	76	82

Table 8.3. Contributions of principal causes of death to changes of life expectancy at birth in Russia in 1992-1994 (years).

I. Males

No.	Causes of Death	1992	1993	1994
1	Infectious and parasitic diseases	-0.05	-0.12	-0.05
2	Malignant neoplasms	0.07	-0.04	0.03
3	Cardiovascular diseases	-0.23	-1.09	-0.68
4	Respiratory diseases	-0.08	-0.28	-0.09
5	Gastrointestinal diseases	-0.10	-0.10	-0.09
6	Other diseases	-0.21	-0.16	-0.15
7	Accidents	-0.84	-1.29	-0.46
8	All causes	-1.44	-3.06	-1.49

II. Females

No.	Causes of Death	1992	1993	1994
1	Infectious and parasitic diseases	-0.01	-0.05	-0.02
2	Malignant neoplasms	-0.02	0.00	0.01
3	Cardiovascular diseases	-0.15	-0.94	-0.53
4	Respiratory diseases	0.02	-0.13	0.02
5	Gastrointestinal diseases	0.03	-0.06	-0.07
6	Other diseases	-0.11	-0.15	-0.07
7	Accidents	-0.25	-0.49	-0.17
8	All causes	-0.53	-1.81	-0.83

Table 8.4. Contributions of principal causes of death to the difference in life expectancy at birth between males and females in Russia (years).

No.	Causes of Death	1992	1993	1994
1	Infectious and parasitic diseases	0.29	0.36	0.38
2	Malignant tumors	1.86	1.68	1.53
3	Cardiovascular diseases	3.86	4.19	4.59
4	Respiratory diseases	0.87	1.03	1.12
5	Gastrointestinal diseases	0.34	0.37	0.41
6	Other diseases	0.50	0.44	0.53
7	Accidents	4.26	4.94	5.12
8	All causes	11.80	13.01	13.68

Table 8.5. Contributions of different age groups to variations in life expectancy at birth in Russia (years).

I. Males

Age Group	1991	1992	1993	1994
0-14	0.11	0.09	-0.11	0.01
15-29	-0.44	-0.24	-0.35	-0.14
30-44	-0.55	-0.55	-0.91	-0.42
45-59	-0.47	-0.53	-1.04	-0.69
60-74	- 0.04	-0.26	-0.54	-0.26
75 and over	-0.08	0.01	-0.12	-0.01
Total	-1.39	-1.48	-3.06	-1.49

II. Females

Age Group	1991	1992	1993	1994
0-14	0.12	0.07	-0.18	0.05
15-29	-0.12	-0.06	-0.10	-0.04
30-44	-0.90	-0.15	-0.30	-0.16
45-59	-0.15	-0.19	-0.52	-0.37
60-74	-0.09	-0.18	-0.42	-0.24
75 and over	-0.07	-0.02	-0.20	-0.06
Total	-0.22	-0.53	-1.81	-0.83

Table 8.6. Changes of life expectancy at birth for males in relation to age groups and principal causes of death (in years).

Age (years)	Cardiovascular Diseases	Accidents	All Causes of Death
1991			
0 - 14	-0.001	-0.057	-0.143
15 - 29	-0.006	-0.083	-0.099
30 -44	-0.008	-0.092	-0.112
45 - 59	-0.008	-0.042	-0.003
60 - 74	-0.042	-0.006	0.080
75 and over	0.000	-0.002	-0.001
All ages	0.034	-0.281	-0.277
1992			
0 - 14	-0.002	0.004	0.089
15 - 29	-0.011	-0.202	-0.244
30 - 44	-0.096	-0.381	-0.554
45 - 59	-0.167	-0.255	-0.523
60 - 74	-0.136	-0.045	-0.260
75 and over	0.004	0.000	0.010
All ages	-0.409	-0.879	-1.482
1993			
0 - 14	-0.003	-0.009	-0.110
15 - 29	-0.024	-0.296	-0.350
30 - 44	-0.192	-0.520	-0.908
45 - 59	-0.411	-0.385	-1.035
60 - 74	-0.357	-0.078	-0.543
75 and over	-0.009	-0.005	-0.116
All ages	-1.086	-0.292	-3.062
1994			
0 - 14	0.001	0.022	0.016
15 - 29	-0.017	-0.101	-0.137
30 - 44	-0.132	-0.156	-0.419
45 - 59	-0.316	-0.185	-0.686
60 - 74	-0.190	-0.036	-0.258
75 and over	-0.026	-0.001	-0.010
All ages	-0.680	-0.456	-1.494

Table 8.7. Change of life expectancy at birth for females in relation to age groups and principal causes of death (years).

Age (years)	Cardiovascular Diseases	Accidents	All Causes of Death
1991			
0 - 14	-0.001	-0.036	-0.106
15 - 29	-0.003	-0.022	-0.044
30 - 44	-0.007	-0.018	-0.033
45 - 59	-0.004	-0.009	-0.005
60 - 74	0.043	-0.001	0.068
75 and over	0.033	0.001	0.040
All ages	0.060	-0.083	-0.080
1992			
0 - 14	-0.001	-0.002	0.073
15 - 29	-0.002	-0.054	-0.063
30 - 44	-0.035	-0.098	-0.148
45 - 59	-0.069	-0.085	-0.188
60 - 74	-0.120	-0.022	-0.182
75 and over	-0.012	-0.002	-0.019
All ages	-0.238	-0.263	-0.528
1993			
0 - 14	-0.001	-0.033	-0.182
15 - 29	-0.008	-0.088	-0.103
30 - 44	-0.072	-0.156	-0.297
45 - 59	-0.242	-0.164	-0.517
60 -74	-0.335	-0.045	-0.420
75 and over	-0.278	-0.005	-0.293
All ages	-0.936	-0.490	-1.812
1994			
0 - 14	0	0,013	0.051
15 - 29	-0,004	-0,026	-0.040
30 - 44	-0,055	-0,053	-0.164
45 - 59	-0,172	-0,076	-0.372
60 - 74	-0.197	-0,019	-0.239
75 and over	-0,099	-0,001	-0.063
All ages	-0,526	-0,163	-0.827

Table 8.8. Life expectancy at birth in various industrial areas of Russia in 1991-1992 and 1993 (years).

Industrial Areas	Males		Females	
	1991-1992	**1993**	**1991-1992**	**1993**
Northern area	61.0	57.7	73.2	71.2
North-western area	61.4	57.2	73.2	70.6
Central area	62.3	59.0	74.1	72.4
Volga-Vyatka area	62.8	60.0	74.6	73.1
Central Black Earth area	62.8	60.8	75.0	73.3
Volga area	63.5	61.0	75.0	72.9
North Caucasus	63.6	61.2	74.2	71.9
The Urals	62.2	59.0	73.7	71.1
Western Siberia	61.7	58.3	73.4	69.6
Eastern Siberia	59.6	56.1	71.9	69.9
The Far East	60.1	57.0	71.8	70.9
Kaliningrad Region	62.1	58.5	72.6	70.9
All Russia	62.0	58.9	73.8	71.9

Table 8.9. Structure of working capacity loss in the Russian population in 1993 in relation to principal causes of death (x 10^3 person-years of working activity).

Class rank	Classes of Death Causes	Loss	Percentage (%)
1	Injuries and poisonings	1434.7	47.1
2	Cardiovascular diseases	320.2	10.5
3	Perinatal diseases	276.8	9.1
4	Malignant tumors	219.4	7.2
5	Respiratory diseases	186.6	6.1
6	Congenital anomalies	169.3	5.5
7	Infectious and parasitic diseases	113.4	3.7
8	Not classified causes	82.3	2.7
9	Diseases of the nervous system and sense organs	67.5	2.5
10	All classes	2879.2	94.4

Table 8.10. Working capacity loss for men and women in Russia in 1993 (x 10^3 person-years of working activity).

Main Causes of Death	Men		Women	
	Loss	Class Rank	Loss	Class Rank
Injuries and poisonings	1100.9	1	333.8	1
Cardiovascular diseases	211.8	2	108.4	4
Perinatal diseases	157.2	3	119.6	3
Respiratory diseases	108.6	4	78.0	6
Malignant tumors	99.6	5	119.8	2
Congenital anomalies	88.9	6	80.4	5
Infectious and parasitic diseases	74.5	7	38.9	7
Not classified causes	56.8	8	25.5	9
Gastrointestinal diseases	43.0	9	24.5	10
Diseases of the nervous system and sense organs	42.0	10	34.5	8
All causes of death	1909.2		983.3	

Table 8.11. Working capacity loss in the population of Russia in 1993 in relation to different causes of death (x 10^3 person-years of working activity).

Class Rank	Class of Causes of Death	Loss	Percentage
1	Injuries and poisonings, including:	1434.7	--
	-Transport injuries	247.0	16.9
	-Homicides	235.7	16.1
	-Suicides and self-inflicted injuries	226.5	15.5
	-Injuries (not specified)	164.1	11.2
	-All other accidents	147.2	10.1
	-Accidental alcohol poisoning	119.2	8.2
	-Accidental drowning	107.9	7.4
	-Other accidental poisonings	76.5	5.2
	Total		90.6%
2	Cardiovascular diseases, including:	320.2	--
	-Ischemic heart disease	101.2	31.1
	-Other heart diseases	70.1	21.5
	-Vascular brain disorders without hypertension	63.7	19.5
	-Cardiosclerotic atherosclerosis	33.5	10.4
	-Acute myocardial infarction	23.5	7.2
	-Chronic rheumatic heart diseases	12.5	3.8
	Total		93.5%

Table 8.12. Working capacity loss for the Russian population due to injuries and poisonings in 1989-1993 (x 10^3 person-years of working activity).

I. Males

Cause of Death	1989	1990	1991	1992	1993
Suicides	1.69	1.79	1.84	2.17	2.71
Homicides	1.15	1.32	1.42	2.06	2.61
Accidental alcohol poisoning	0.40	0.48	0.51	0.83	1.33
Other accidental poisonings	0.51	0.50	0.54	0.62	0.74
Other cirrhoses of liver	0.073	0.081	0.085	0.093	0.152
Chronic alcoholism	0.025	0.039	0.036	0.049	0.124
Death from alcoholic intoxication	-	0.65	0.69	1.06	1.69

II. Females

Cause of Death	1989	1990	1991	1992	1993
Suicides	0.33	0.36	0.38	0.52	0.69
Homicides	0.35	0.37	0.38	0.42	0.49
Accidental alcohol poisoning	0.09	0.11	0.11	0.18	0.34
Other accidental poisonings	0.23	0.22	0.23	0.23	0.32
Other cirrhoses of liver	0.052	0.061	0.061	0.072	0.107
Chronic alcoholism	0.006	0.008	0.009	0.013	0.043
Death from alcoholic intoxication	-	0.14	0.14	0.23	0.43

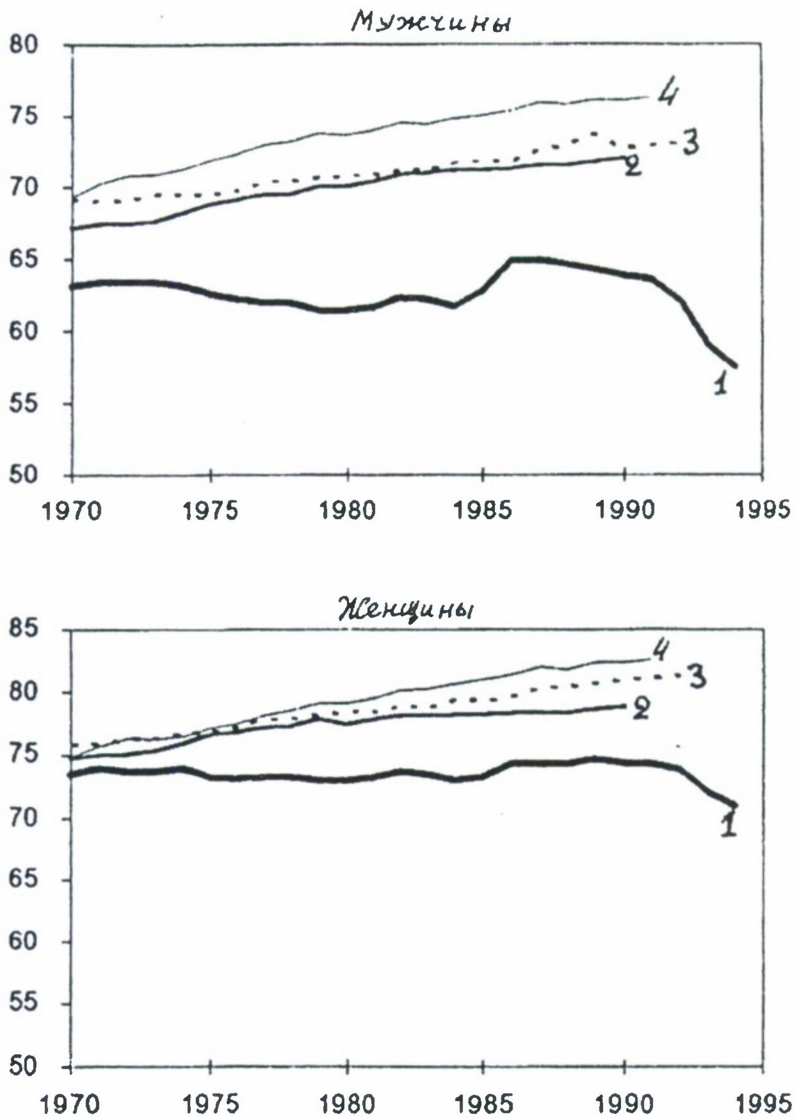

Figure 8.1. Life expectancy in Russia (**1**), the USA (**2**), France (**3**), and Japan (**4**) in 1970-1994 (upper table for males/lower table for females).

PART II. RADIATION RISK IN THE RUSSIAN FEDERATION

9.0: RADIATION RISK RELATIVE TO DOSE LIMITS

9.1 INTRODUCTION

This section describes the methodological basis for assessing radiation risk to which the Russian population is exposed in view of radiation contamination of some of Russia's territories. The procedure we used had two stages. First, we estimated the distribution of radiation doses among the population affected, and then the risk of adverse effects was calculated on the basis of these dose estimates. It was thought useful to start by estimating the radiation risk that corresponds to the new dose limits for the public and personnel (occupational workers). These dose limits were established by the Radiation Safety Standards adopted in 1996 (1), which replaced the standards adopted in 1987 (2). We analyzed the currently used approaches and procedures, as well as the available initial data for assessing risk parameters. The analysis has shown that the approach of the International Commission on Radiological Protection (ICRP) set forth in Publication 60 (3) is the most reliable to date.

9.2 POPULATION RISK ASSESSMENT WITH CONSIDERATION OF THE DEMOGRAPHIC STRUCTURE

It is well known that risk assessment may closely depend on the initial demographic characteristics of the population in question (3-5). For instance, the risk assessments made by the ICRP were obtained for the postwar population of Japan and extrapolated to other populations. At the same time, however, the ICRP stressed that as there are always some competing potential causes of death, one has to proceed from the pattern of mortality typical of the population studied. Therefore, we have used the system of risk indices elaborated in ICRP Publication 60 and applied this approach to the demographic conditions in Russia (6, 7). We studied the initial basic demographic data. The mortality rates from the "USSR Demographic Yearbook, 1989" (8) were taken as the reference base. For the purpose of the present work we calculated the age-specific mortality coefficients for men and women taking account of their respective percentages (47.8% and 53.2%) in the total population number. Figure 9.1 shows the age dependence thus calculated of the death probability rates for the Russian situation and, for comparison, an analogous dependence used by the ICRP (3). One can see that the age-related death probability rates for Russia using 1989 as the reference are twice and even higher than the similar rates used in the ICRP calculations. Figure 9.2 gives, for the Russian population as a whole, the probability to survive to a given age and the probability density of dying at this age.

9.3 A MULTIPLICATIVE MODEL ASSESSMENT OF RISK PARAMETERS

In the range of radiation doses of interest to us there is no reliable statistic data on radiation risk. The lacking data are usually obtained by extrapolation from the region of higher doses for which experimental, clinical, and epidemiological information is available. For such an extrapolation use is

made of an additive and/or a multiplicative phenomenological model (3-5). The data at our disposal indicate that the multiplicative model is preferable when estimating the risk of death from radiation-induced malignant tumors (5). In this model, the time distribution of the probability of additional cases of tumors is similar to the distribution of the incidence of spontaneous tumors. This makes it possible to use a constant coefficient in passing from the age dependence of mortality from spontaneous tumors to the age dependence of mortality from radiation-induced tumors (5). Therefore, the multiplicative model is also called a model of relative risk.

In order to use a multiplicative model one has to know the age-specific mortality rates due to cancer for the Russian population. These data are shown in Figure 9.3, curve 2. Unfortunately, they refer only to the range of 30-70 years and to all types of cancer without separation of leukemia from non-leukemia. Figure 9.3 also demonstrates the same dependence calculated with data from the ICRP (curve 3). The values of age-specific mortality rates from cancer for Russia are 1.6-fold higher on the average than those calculated with ICRP data. In our calculations, for all ages we used curve 2, which was extrapolated to age ranges under 30 and over 70 by analogy with curve 3.

Figure 9.4 shows the unconditional probability rate, based on the multiplicative model, of death from radiation-induced cancer after a single dose of 70 mSv (curve 1) and 350 mSv (curve 2) received at age zero.

Figure 9.5 gives the multiplicative model-based conditional probability rates of death from leukemia (curve 1) and non-leukemia (curve 2) for individuals of the same age chronically exposed to an annual dose of 1 mSv all their lives from age zero. Similar curves for leukemia (curve 1) and non-leukemia (curve 2) are shown in Figure 9.6 for the conditions of chronic exposure at the ages of 18-58 years to an annual dose of 20 mSv.

Using the above-indicated risk parameter values calculated by the multiplicative model, we estimated the radiation risk after a single exposure of the population to 70 and 350 mSv and also the radiation risk for chronic population exposure to annual doses of 1 and 5 mSv. We also estimated the radiation risk for occupational exposures of personnel at the ages of 18-58 years to annual doses of 20 and 50 mSv (6, 7, 9).

9.4 SINGLE IRRADIATION OF THE POPULATION

We give here the calculated values of radiation risk (6, 7, 9) after a single exposure of the population at age zero with consideration for age-specific mortality rates for the conditions of Russia (8). The calculations were conducted for acute irradiation doses of 70 and 350 mSv. These values of acute irradiation dose were chosen for the following reason. The dose limit of 70 mSv corresponds to the dose that will accumulate over one's life by the age of 70 years if the annual exposure dose is 1 mSv. The dose limit of 350 mSv was introduced by the USSR Ministry of Health in January 1990 and it included doses of internal and external irradiation that had been received by the population beginning from April 26, 1986, i.e., from the first day of the Chernobyl disaster. That limit on individual dose built up over a person's lifetime to age 70 was taken to be a maximal measure of the risk of stochastic health effects. It is of interest to compare the levels of risk of death for the same doses of irradiation but under different irradiation regimes: single (acute) or multiple (chronic) exposures. Table 1 lists the basic risk parameters after a single exposure at age zero to 70 and 350 mSv. Irradiation at age

zero results in realization of every delayed health effect from a single radiation exposure to the maximum extent. In assessing the risk after a single irradiation in other age groups, one should bear in mind that some of the delayed effects will not have time enough to manifest themselves during the remaining lifetime. So the data in Table 9.1 are upper estimates of risk. These data show that (1) the life expectancy at birth for the specific social and economic conditions of Russia is 69.1 years and that (2) after single exposures to 70 or 350 mSv the calculated reduction of forthcoming life is 0.15 or 0.87 year, respectively. Furthermore, after a single exposure to 70 or 350 mSv, the attributable probability of death from radiation-induced cancer is 1.25% or 6.0%, respectively, and the average annual risk of death is 1.8×10^{-4} or 8.8×10^{-4}, respectively.

Although the relative reduction of forthcoming life after a single exposure at age zero is not large, the average annual risk is considerable, particularly after the dose of 350 mSv.

Table 9.2 compares the basic parameters of radiation risk after a single exposure to a dose of 70 mSv at age zero for a standard ICRP population and a Russian population. One can see an appreciable difference in life expectancy between the former (74.8 years) and the latter (69.1 years). While the difference in reduction of lifetime can be neglected, the difference in attributable lifetime probability of death from radiation-induced cancer is quite significant. This observation confirms once more that the specific demographic situation in Russian regions of interest should be taken into account in risk assessments. One can see that there are substantial differences in attributable lifetime probability of death from radiation-induced cancer between the two indicated populations. For the Russian conditions, this value is higher by 22% than for the standard ICRP population.

9.5 CHRONIC IRRADIATION OF THE POPULATION AND PERSONNEL

To evaluate the effect of the demographic structure of a chronically irradiated population on the risk levels we compare our summarized data on radiation risk with the data of the ICRP (Table 9.3). For a lifetime radiation exposure to an annual dose of 1 mSv, the attributable lifetime probability of death from radiation-induced cancer is 5×10^{-3} for a Russian population and 4×10^{-3} for a standard ICRP population. At a dose of 5 mSv this probability is about 2.5×10^{-2} and 2×10^{-2}, respectively. The difference is quite noticeable.

Loss of life expectancy at an annual dose of 5 mSv is 0.31 year per person for Russia and 0.27 year for the standard ICRP population. But the relative reduction of lifetime is 0.45% for Russia and only 0.36% for the standard ICRP population, which is explained by the difference in average lifetime in the two cases. At the same time, the loss of lifetime from radiation-induced cancer at an annual dose of 5 mSv is 12.6 years for Russia and 13.5 years for the ICRP population; thus relative loss of life expectancy appears identical (18%).

Summarized calculated data on occupational exposure at the age of 18-58 for the population of Russia and at the age 18-65 for the standard ICRP population to annual doses of 20 and 50 mSv are given in Table 9.4. The attributable lifetime probability of death from radiation-induced cancer is 4.26×10^{-2} at a dose of 20 mSv and 1×10^{-1} at 50 mSv for the Russian population. For the standard ICRP population these values are somewhat lower. Loss of expected life at the age of 18 from a subsequent annual dose of 20 mSv is about half a year; at an annual dose of 50 mSv this loss is 1.24 year.

9.6 CONCLUSIONS

Comparison of summarized data on radiation risk for the Russian population and for the standard ICRP population suggests the conclusion that the basic risk parameters for the former are somewhat higher than for the latter. For example, in the case of life-long exposure to the annual doses of 1 and 5 mSv and in the case of adult population exposure to the annual doses of 20-50 mSv, the values of the attributable lifetime probability of death from cancer are about 25% and 17-19% higher, respectively, for Russia than for the standard ICRP population. Thus, a comparison of the calculated radiation risk parameters for the Russian population at dose limits that had been earlier adopted in the official Radiation Safety Standards (5 mSv/year for the public and 50 mSv/year for personnel) (2) and also at dose limits adopted in the new Standards (1 mSv/year and 20 mSv/year, respectively) (1) with the risk parameters estimated by the ICRP show certain discrepancies in radiation risk values. These discrepancies seem to be accounted for by the differences in the demographic structure of the Russian population and the standard population used by the ICRP.

Of interest is the influence of irradiation time distribution on risk magnitude. In the case of a single exposure at birth, the attributable death probability increases 2.5-fold compared to the case of chronic exposure, and the reduction of expected lifetime increases up to 2.8-fold. A single exposure at a dose of, e.g., 350 mSv, at the beginning of life leads to more pronounced, deleterious health effects compared to a chronic exposure at the same dose. This must be taken into consideration when evaluating the consequences of an emergency irradiation.

Table 9.1. Principal parameters of risk after a single exposure at age zero for the Russian population.

Parameter	Dose, mSv		
	0	70	350
Attributable lifetime probability death from radiation-induced cancer, %	-	1.25	6.0
Life expectancy, years	69.1	69.0	68.2
Reduction in life expectancy, years	-	0.15	0.87

Table 9.2. Comparison of principal parameters of radiation risk after a single exposure at age zero for a standard population and the population of Russia.

Parameter	No Exposure	Exposure to 70 mSv		
	ICRP Russia		ICRP	Russia
Attributable lifetime probability of death from radiation-induced cancer, %	-	-	1.02	1.25
Life expectancy, years	74.8	69.1	74.6	9.0
Reduction in life expectancy compared to background, years	-	-	0.16	0.15

Table 9.3. Summarized values of average radiation risk parameters for men and women exposed to life-long irradiation from age zero.

Parameter	ICRP Calculation		Our Calculation	
	Annual doses, mSv			
	1	5	1	5
Attributable lifetime probability of death from radiation-induced cancer, %	0.40	1.99	0.50	2.46
Loss of life expectancy at age zero, years	0.050	0.27	0.56	0.31
Loss of life expectancy due to death from cancer, years	13.4	13.5	11.2	12.6

Table 9.4. Summarized values of average radiation risk parameters for men and women exposed at the age of 18-65 (standard ICRP population) and 18-58 (Russian population).

Parameter	ICRP Calculation		Our Calculation	
	Annual doses, mSv			
	20	50	20	50
Attributable lifetime probability of death from radiation-induced cancer, %	3.57	8.56	4.26	10.0
Loss of life expectancy at age 18, years	0.46	01.11	0.51	1.24
Loss of lifetime due to death from cancer, years	12.7	13.0	12.0	12.4

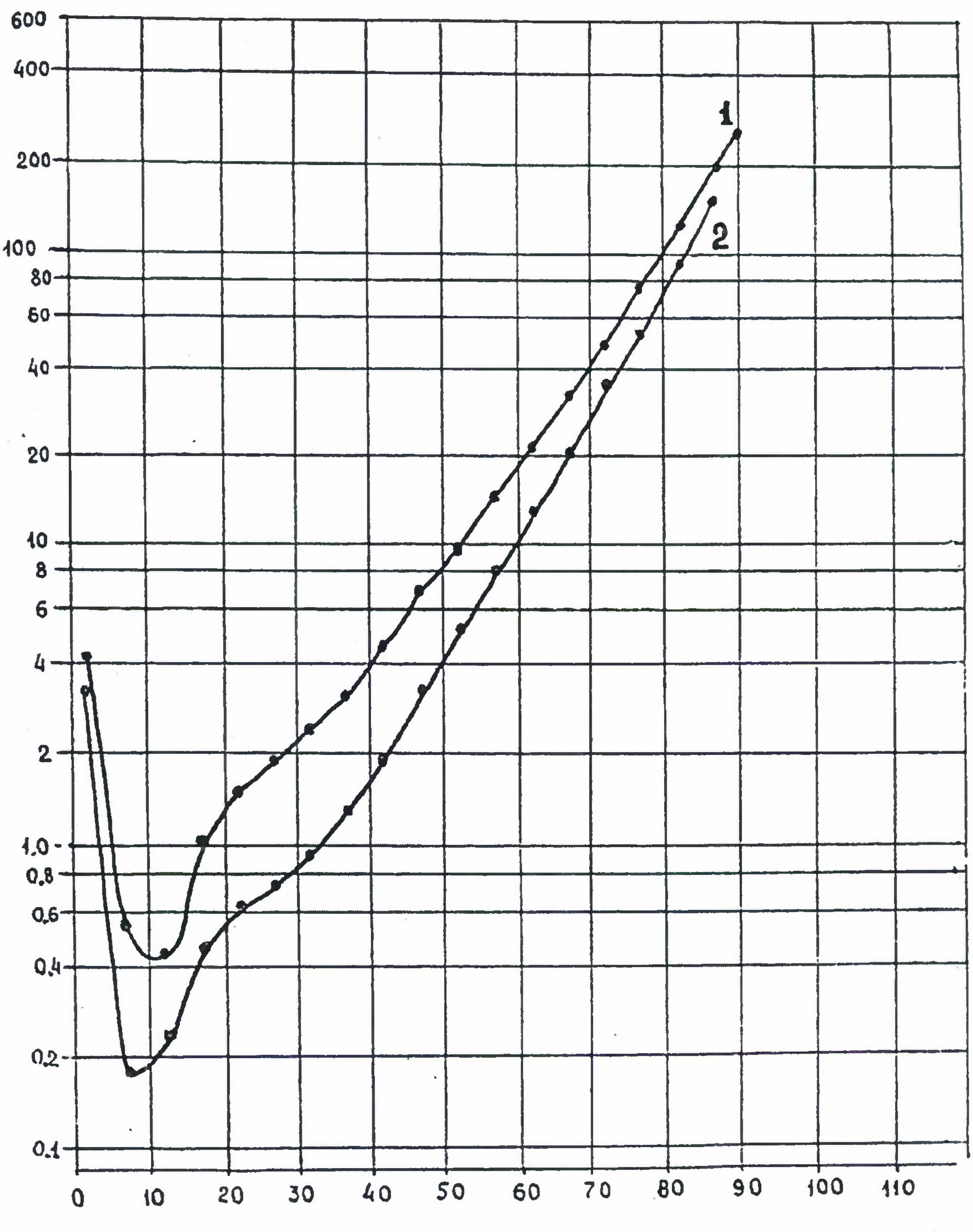

Figure 9.1. The age-specific dependence of mortality rates for the conditions of Russia (1) and for the standard ICRP population (2). Abscissa: age, years; ordinate: mortality rate, 10^{-3} $year^{-1}$.

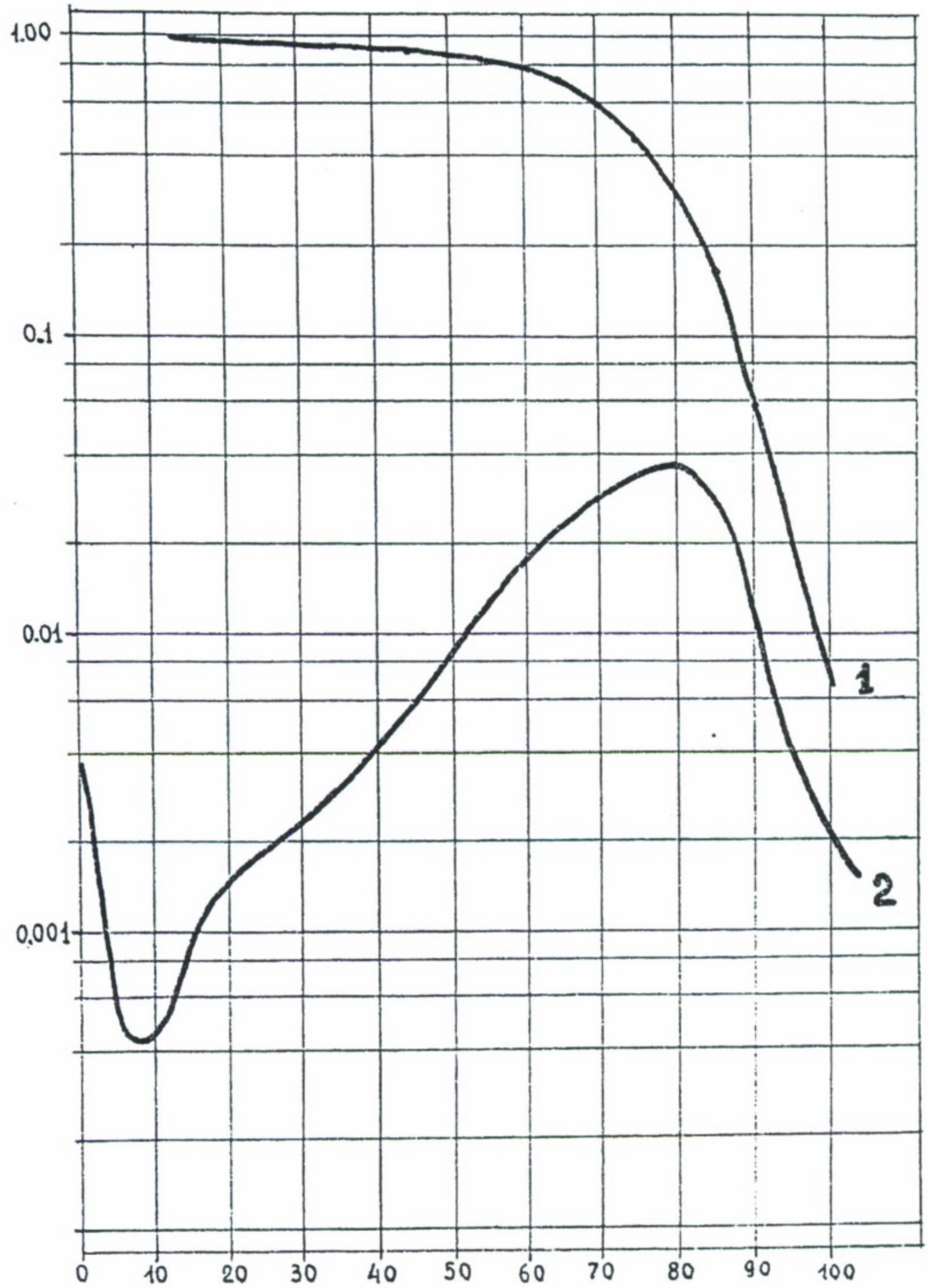

Figure 9.2 The probability of survival to a given age (1) and the probability density of dying at this age (2) for the population of Russia. Abscissa: age, years; ordinate: mortality rate, year^{-1}.

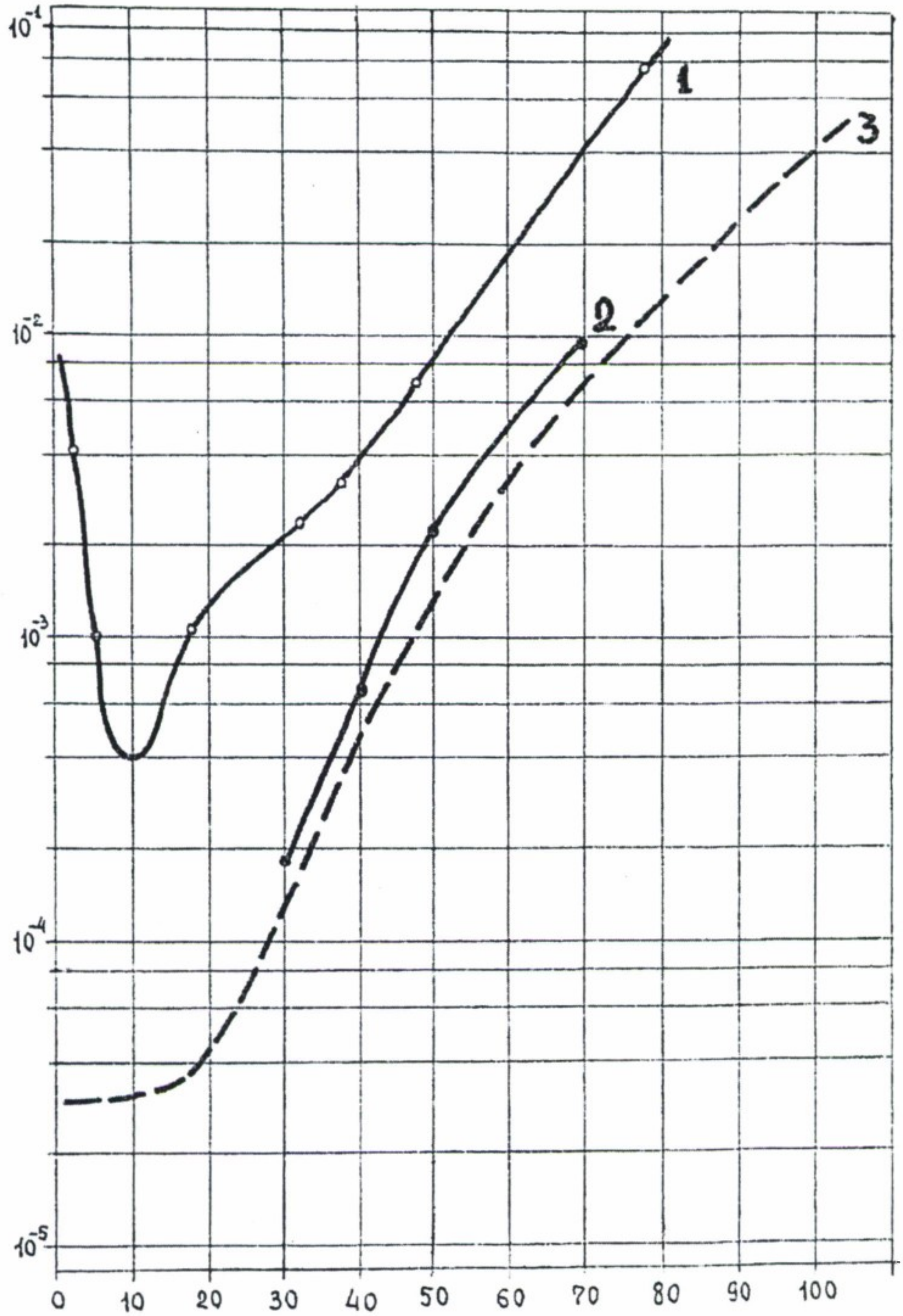

Figure 9.3. The age-specific dependence of mortality rate coefficients for the Russian conditions (1), the age-specific rates mortality rate coefficients for the Russian population from cancer (2), and the same coefficients calculated using ICRP data (3). Abscissa: age, years; ordinate: mortality rate, year^{1}.

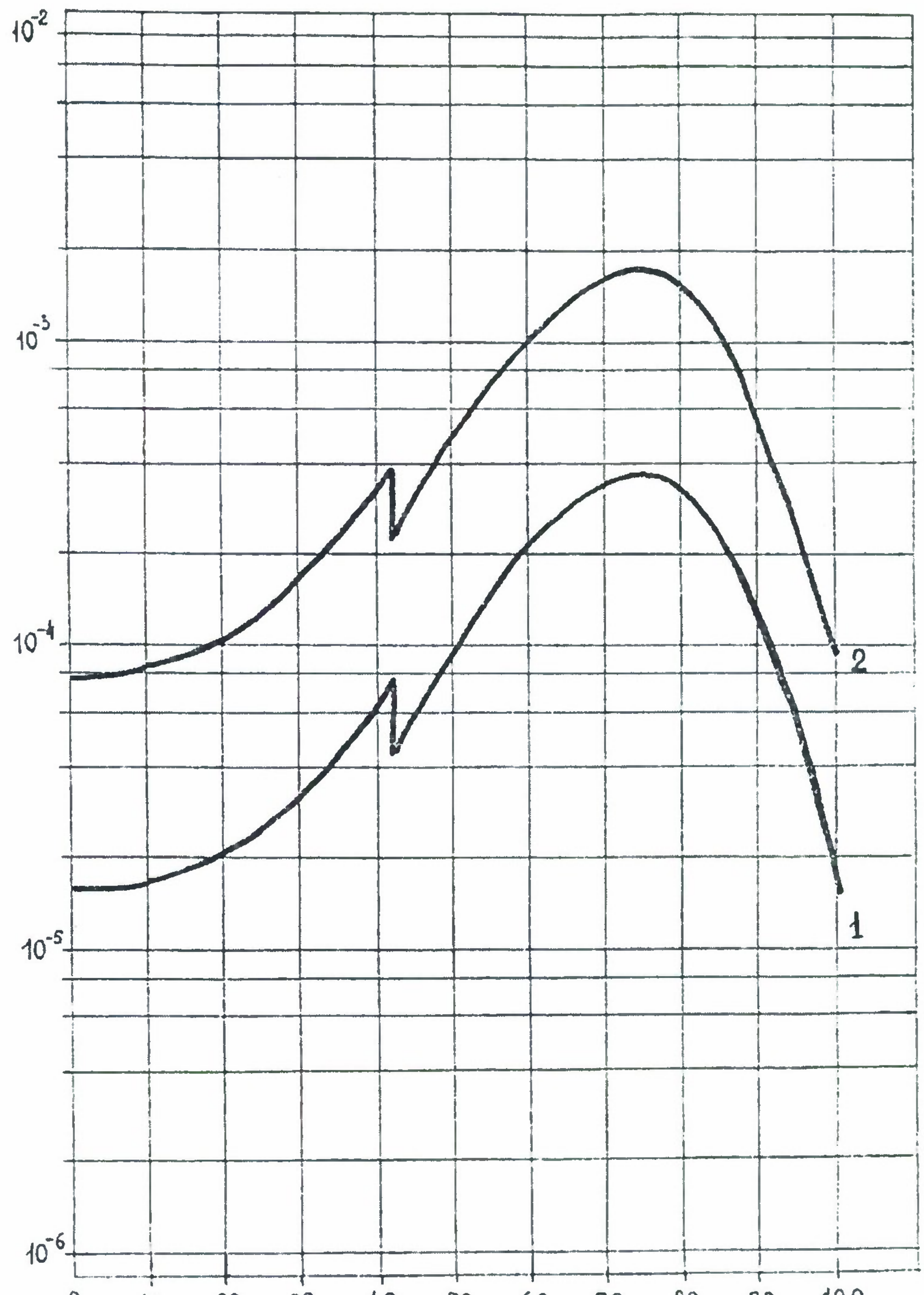

Figure 9.4. The density of unconditional probability of death from radiation-induced cancer after a single exposure at age zero to a dose of 70 mSv (1) and 350 mSv (2) for the Russian conditions. Abscissa: age, years; ordinate: probability density.

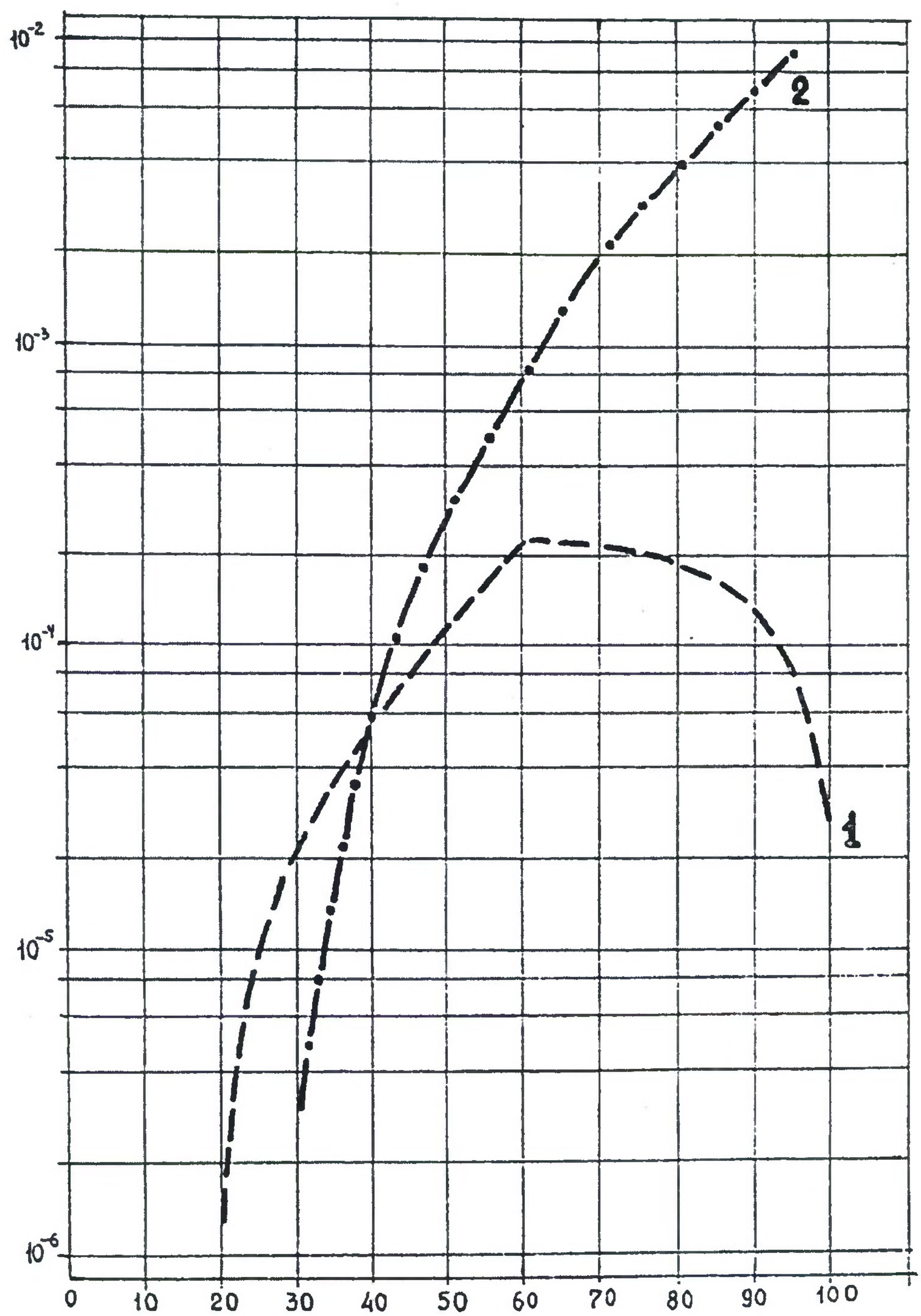

Figure 9.5. The density of conditional probability of death from leukemia (1) and non-leukemia (2) for individuals of the same age exposed to an annual dose of 1 mSv during all their life beginning at age zero, for the Russian conditions. Abscissa: age, years; ordinate: probability density.

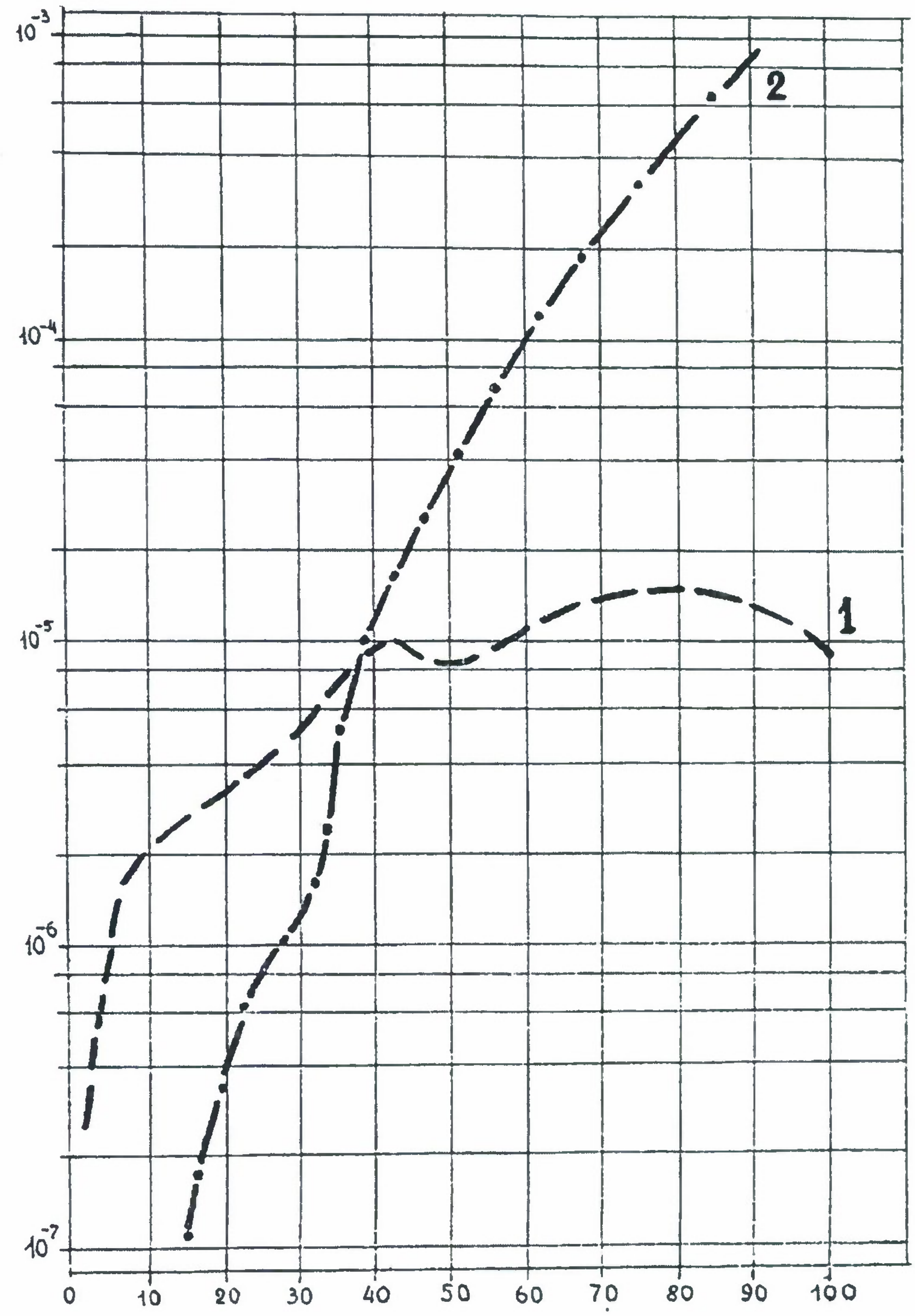

Figure 9.6. The density of conditional probability of death from leukemia (1) and non-leukemia (2) for personnel at the age of 18-58 years chronically exposed to a dose rate of 20 mSv/year, for the Russian conditions. Abscissa: age, years; ordinate: probability density.

10.0: CHERNOBYL-RELATED RADIATION RISK FOR THE PUBLIC

10.1 INTRODUCTION

Owing to the Chernobyl disaster in April 1986, an enormous amount of radioactive substances totaling up to about 50 MCi (not including inert gases) was released into the atmosphere (1). The predominant contaminant among the long-lived radionuclides was cesium-137. In Belarus, Ukraine, and Russia (the most affected countries) alone, the total area contaminated with ^{137}Cs at a density of more than 1 Ci/km^2 measured 131,000 km^2 (1). The radioactive contamination of this territory was highly non-uniform and spotty. At the time of the Chernobyl disaster, the territory had about four (4) million residents, including nearly one (1) million children (1).

There are three main radioactive contamination spots within the European part of the former USSR: Central, Bryansk-Belarus, and Kaluga-Tula-Orel (2). Of these the Central spot is fully contained within Ukraine and Belarus. In the Russian Federation, the Chernobyl-related contamination with a surface contamination density exceeding 1 Ci/km^2 is found in four republics and 19 regions and covers 57,650 km^2, which comprises 1.6% of European Russia (3). The residents of these areas are still exposed to external and internal irradiation by the long-lived radionuclides ^{137}Cs and ^{90}Sr and by the transuranic elements ^{238}Pu, ^{239}Pu, ^{240}Pu, and others. According to data collected through 1995, the external irradiation is primarily due to gamma radiation of ^{137}Cs deposited in the soil, and the internal irradiation is due to the intake of ^{137}Cs in locally produced food and, to a smaller degree, of ^{90}Sr and aerosols of transuranic elements (3).

This section deals with risk analysis only for residents of those regions of Russia which were directly affected by the Chernobyl disaster.

10.2 RADIOACTIVE CONTAMINATION OF RUSSIAN TERRITORIES AS A RESULT OF THE CHERNOBYL ACCIDENT

The Bryansk, Tula, Kaluga, and Orel regions are among the most heavily contaminated areas of the Russian Federation. In more than 90 settlements of the Bryansk Region, the density of surface contamination with ^{137}Cs ranged from 15 to 40 Ci/km^2. In the Tula Region, the ^{137}Cs surface contamination density ranged from 5 to 13 Ci/km^2 in 120 settlements. In the Kaluga and Orel regions, such settlements number 66 and 14, respectively (3). The distribution of settlements in the Russian Federation according to density of surface contamination with ^{137}Cs as of January 1996 is given in Table 10.1 (3). These data cover 14 regions of the European Russia.

The collection of detailed data on radioactive contamination of Russian regions with ^{137}Cs was completed by 1995. Zones with a surface contamination density exceeding 1 Ci/km^2, which included the major cesium spots, were accurately determined (Table 10.2) (4). It was found that about 50,000 km^2 of Russian territory was contaminated with ^{137}Cs at a density from 1 to 5 Ci/km^2, 1,900 km^2 at 15 to 40 Ci/km^2, and 310 km^2 at more than 40 Ci/km^2. The population sizes in regions with various levels of contamination with ^{137}Cs for 1995 (6) are shown in Table 10.3. The data from Tables 10.1, 10.2, and 10.3 demonstrate that the level of residual soil contamination with ^{137}Cs in 1995 was still very high in certain regions of Russia.

Soil contamination with ^{90}Sr and with transuranic elements is not as widespread over the Russian territory as that with ^{137}Cs (4). The ^{90}Sr deposition density is 0.7-1.0 Ci/km^2 in the western Bryansk Region and up to 0.4-0.5 Ci/km^2 in the Tula Region; the average global ^{90}Sr deposition density over the East European Plain is 0.02 to 0.04 Ci/km^2 (4). In some areas of the Bryansk Region, soil contamination with $^{239,240}Pu$ is 0.01 Ci/km^2 and with ^{238}Pu and ^{241}Am is 0.015 Ci/km^2 (4).

Detailed information on the density of surface contamination with ^{137}Cs, ^{90}Sr, ^{239}Pu, and ^{240}Pu for practically all settlements located in the Chernobyl-contaminated zones of Russia can be found in Reference 5.

10.3 INTERNAL IRRADIATION OF RESIDENTS

The internal post-Chernobyl doses were due to iodine, cesium, and strontium intake with foodstuffs. In May 1986, the principal internal irradiation factor was ^{131}I, which accumulated in the thyroid. Since the summer of 1986, the principal contributors to internal doses have been radioactive isotopes of cesium ingested with food. The contribution of strontium isotopes to the internal irradiation dose is no more than 1-5%. Even smaller (by an order of magnitude) is the contribution of plutonium and americium isotopes (7).

10.3.1 INTERNAL IRRADIATION WITH ^{131}I

The dose to the thyroid from incorporated ^{131}I was determined by measuring the content of this radionuclide in the thyroid taking into consideration changes in the radiological situation in this particular area and also the countermeasures taken (7). More detailed data on the radioactive contamination of Russian territory can be found in reference 8.

The highest absorbed doses to the thyroid were received by the residents of the Krasnogorsk district of the Bryansk region. The absorbed doses to the thyroids of children below three years of age reached 2500-2700 mGy and to those of adults were 300-900 mGy (7). An age-specific analysis of absorbed doses to the thyroid revealed differences between the urban and rural populations (Table 10.4) (7).

The collective dose to the thyroid from incorporated ^{131}I for residents of some selected regions was found by summing up the collective doses in each settlement. The latter were calculated as sums of products of the average absorbed dose by the number of residents in each of the three age groups at the time of the Chernobyl disaster: (1) children under seven years, (2) seven to 17 years, and (3) 18 years and older. The results of these calculations are given in Table 10.5 (7).

The highest collective doses to the thyroid - about 60,000 person-Gy - were received by the residents of the Bryansk and Tula regions. Much lower collective doses were received by the residents of Orel (15,000 person-Gy) and Kaluga (10,000 person-Gy) regions. As the value of the collective dose is the product of the average absorbed dose and the number of individuals which received an absorbed dose, the greatest contribution to the collective dose in a region comes from territories with a low contamination level but a high population density. For example, the collective doses received in the Bryansk and Tula regions turned out to be equal in magnitude, although the soil contamination level in the Tula Region is much lower than in the Bryansk Region. At the same time, in the Bryansk

Region, the exposure of 7.5% of the residents of the most heavily contaminated ("controlled") area makes up about 40% of the collective dose of the entire region (7).

10.3.2 INTERNAL IRRADIATION WITH Cs AND Sr RADIONUCLIDES

The whole-body internal doses from Cs and Sr radionuclides to residents of the contaminated territory were estimated in reference 7. Two methods were used: (1) calculating the intake of the radionuclides from measurements of their contents in foodstuffs, and (2) calculating their intake from direct measurements of radionuclide contents in the organism.

The results of the calculations for the adult rural population of Russia are summarized in Table 10.6 (7). The age of an adult at the time of the Chernobyl disaster was taken to be 18 years and the duration of exposure after the disaster was assumed to be 52 years. These data refer to various post-Chernobyl time intervals and were normalized to the soil contamination density for ^{137}Cs in 1986. Two types of soil were considered: soddy-podzolic sandy and black-earth. As shown by Table 10.6, the internal dose from the Cs and Sr radionuclides mainly depended on their intake within the first eight years after the disaster. A considerable effect on the internal dose was exerted by the prevailing soil type: continuous irradiation levels are six times lower in black-earth areas than in areas with poor soddy-podzolic soils.

10.4 EXTERNAL IRRADIATION OF RESIDENTS

In the first days after the Chernobyl disaster, the predominant contribution to the external dose to the population came from gamma-radiation of $^{132}Te + ^{132}I$ and ^{131}I (about 70% of the dose by the 1st of May, 1986). After 3 months, the external radiation was nearly totally determined by ^{134}Cs and ^{137}Cs. By the 1st of January, 1987, these nuclides were responsible for about 92% of the dose, and the rest came from ^{106}Ru and ^{103}Ru (7).

Additional factors influencing external radiation doses are the living and working conditions of the rural and urban population. The situation was thoroughly studied and the affected population was divided into relatively uniform groups for which the average annual coefficients of diminution of the absorbed external gamma-radiation dose were found. As a result, average effective external doses were calculated (Table 10.7) for rural and urban residents (7). These values were normalized to the surface contamination density for ^{137}Cs referred to the time of the accident. It was found that, under equal soil contamination densities, the rural residents receive on the average doses which are 1.7-fold higher than those received by the urban population. The latter spend more time inside various types of buildings, in particular brick or concrete houses, and therefore are better protected against external irradiation.

Table 10.7 shows that the dose accumulation proceeds at a relatively high rate. For instance, within the first year post-Chernobyl the average dose reached 20% of its expected magnitude after 70 post-Chernobyl years (1986-2056), and within the first nine years the average accumulated dose comprised 50% of the expected lifetime dose (7). At a contamination density of 1 Ci/km^2 (37 kBq/m^2), the average accumulated dose over the first year post-Chernobyl was 0.48 mSv for rural residents and 0.30 mSv for urban residents.

Table 10.8 presents the average effective external doses the population is expected to accumulate within 70 years post-Chernobyl (1986-2056) for various ^{137}Cs soil contamination densities.

10.5 TOTAL EFFECTIVE DOSE OF EXTERNAL AND INTERNAL IRRADIATION

The total effective dose of external and internal irradiation was estimated for residents of some settlements in the Bryansk and Tula regions (7). The dose accumulated from 1986-1994 was calculated using direct measurements of individual doses and the radionuclide contents in the organism. The doses for 1995-2056 were estimated using the models described in (7). The data obtained are given in Table 10.9. Analysis of the data from Table 10.9 demonstrates that the dependence of the effective dose on the ^{137}Cs surface contamination density is not quite clear-cut. The dependence of the external dose on the contamination density is close to linear. The internal dose depends quite strongly on ecological and social factors. A marked effect is produced by the type of soil. In the Bryansk Region, the predominant soil is soddy-podzolic, while in the Tula Region, black-earth soil prevails. But even within one region the ratio of external to internal radiation doses varies considerably depending on the prevailing agricultural techniques used.

Table 10.9 shows that in the worst case (Zaborye settlement in the Bryansk Region), where the surface contamination density reaches 4.3 MBq/m^2 (about 116 Ci/km^2), the total effective dose over 70 years (from 1986 to 2056) will be about 310 mSv. At a much lower contamination density of 0.3 MBq/m^2 (about 8 Ci/km^2), as in the Kamynino settlement of the Tula Region, the total effective dose over 70 years should not exceed 20 mSv.

The principal components of the total effective radiation dose for the Russian population in contaminated territories are gradually decreasing in a monotonic way. For instance, from the first post-Chernobyl year to 1991, the external dose diminished by 5 to 10 times, the internal dose by 10 to 100 times, and the total dose diminished by 10 to 20 times. The subsequent dose reduction proceeded much more slowly, at an annual rate of 10-20% from 1991 to 1994. In the following years the primary contributor to the internal radiation dose of the population was the radionuclides of cesium in natural food products such as wood berries and lake fish. (7).

10.6 RISK ASSESSMENT FOR INTERNAL IRRADIATION

As follows from Table 10.9, the considerable absorbed doses received by the population could be due to ingested iodine radionuclides. The highest doses to the thyroid were recorded in children aged 1 to 3 living in the Bryansk and Kaluga regions. In most cases these doses were in the range from 0.01 to 2.2 Gy, but sometimes they reached 10 Gy and above (2).

By 1994, in the Bryansk and Kaluga regions, the incidence of thyroid cancer in children exceeded the pre-Chernobyl level by 45 times. A positive correlation was found between the level of thyroid irradiation and the incidence of identified thyroid cancers among children and teenagers living on lands with an average soil contamination by ^{137}Cs from 3.7 kBq/m^2 (0.1 Ci/km^2) to 185 kBq/m^2 (5 Ci/km^2) and above. It was established that in 47% of thyroid cancer cases, the most probable values of individual doses to the thyroid ranged from 200 to 2700 mGy; in the remaining cases these doses were 50 mGy and lower (2).

According to estimates in reference 7, the additional (i.e. above the background level prior to 1986) cases of thyroid cancers that can be attributed to radiation comprise (expressed as percent of the background level) 5-10% in the Bryansk and Tula regions and 2-5% in the Orel and Kaluga regions. The only exception is a very heavily contaminated part of the Bryansk Region (the so-called "controlled" territories), where this percentage can reach 20-40%.

Estimates of the risk of radiation-induced thyroid cancer from reference 9 have shown that the attributable lifetime risk of cancer for children from the contaminated territories of the Bryansk Region is 44% (that is, nearly every other cancer will be radiation-induced), and for children from the Kaluga Region this lifetime risk is 26%. It is indicated that the absorbed dose from the incorporated ^{131}I to the thyroid is about 2.2-fold more for residents of the Bryansk Region than for those of the Kaluga Region. For children and teenagers, this ratio is about 3.2 times. It should also be noted that the background thyroid cancer morbidity in the Bryansk Region is much higher (especially in females) than in the Kaluga Region, which is considered to be a relatively safe territory (compared to the rest of Russia) as regards thyroid cancer (9).

Thus, the data from references 2, 7, and 9 suggest the conclusion that the individual annual risk of thyroid cancer for children and teenagers which lived on the lands most heavily contaminated (more than 30 Ci/km^2) till the summer of 1986 does not and will not exceed 4×10^{-5} and 7×10^{-5} for males and females, respectively.

10.7 RISK ASSESSMENT FOR EXTERNAL IRRADIATION

In assessing radiation risk for the population of Russia we resort to the data from Table 10.9. By using the values of the total effective dose, whose major part comes from external irradiation, we have thereby also included, without large errors, a certain contribution of internal irradiation by cesium. (The contribution of strontium is considered insignificant.) Transition from effective dose to radiation risk was performed by means of data from Table 9.3. According to these data, the attributable lifetime probability of death from radiation-induced cancer in the case of lifetime exposure is 0.5% per millisievert per year. These calculations yielded data (summarized in Table 10.10), which indicate rather high levels of risk for residents of the settlements studied.

The expected late stochastic health effects for the Russian population living on contaminated territories are described in reference 2. The authors used the age distribution of the population. The dose was calculated for territories with surface contamination densities ranging from 555 to 740 kBq/m^2 (it is estimated that about 150,000 persons now live on these territories). The lifetime dose for the age distribution used was about 125 mSv. It is shown that the total number of radiation-induced deaths from cancer within 60-70 years after the Chernobyl disaster will reach 500. This implies that the average individual annual radiation risk is 4.3×10^{-5}. This value is in agreement with our estimates (Table 10.10) and with the data from reference 10.

10.8 CONCLUSIONS

The estimates of radiation risk given here take into account the demographic structure of the population of the Russian Federation. In the future, these estimates must be refined by gaining access to local medical and demographic data for each particular area.

An important feature of radiation risk is the substantial contribution of stochastic effects distributed over time (sometimes over tens of years). This is what distinguishes radiation risk from other kinds of risk considered in Part I. It should be noted that despite the fact that more than ten years have elapsed since the time of the Chernobyl disaster, for most of the late stochastic health effects we have observed only the initial section of the ascending curve of radiation-induced disease, characterized by rather low statistical confidence level against the background of high incidence of spontaneous diseases. The existence of highly probable delayed health effects makes a comparison of radiation risk with any other risk from external factors difficult.

The lack of data on age distribution of radiation risk among the residents of the contaminated regions of Russia is an important drawback of the presented radiation risk assessment.

Finally, it should be noted that these risk estimates do not take account of the heterogeneity of the population considered with respect to radiosensitivity. It is well known that any population includes hyper radiosensitive subpopulations. These groups may make an appreciable contribution to the general radiation risk. This point was dealt with by the author in reference 11 and will be examined in detail in Section 13.

Table 10.1. Post-Chernobyl distribution of the number of settlements in Russia according to density of soil contamination with ^{137}Cs (as of January 1996).

No.	Area	Total Number of Settlements	Soil Contamination Density, Ci/km^2			
			<1	1-5	5-15	15-40
1	Bryansk region	2,022	1,166	505	260	91
2	Tula region	2,370	1,099	1,151	120	-
3	Kaluga region	610	267	277	66	-
4	Orel region	1,575	709	852	14	-
5	Ryazan region	556	264	292	-	-
6	Voronezh region	1,208	867	241	-	-
7	Belgorod region	550	327	223	-	-
8	Kursk region	1,116	925	191	-	-
9	Lipetsk region	215	128	87	-	-
10	Leningrad region	160	75	85	-	-
11	Mordovia republic	395	351	44	-	-
12	Penza region	120	96	24	-	-
13	Ulyanovsk region	133	125	8	-	-
14	Tambov region	123	117	6	-	-

Table 10.2 Chernobyl-related contamination with ^{137}Cs in various Russian territories as of August 1995.

Region or Republic	Total area (x 10^3 km^2)	Area contaminated with ^{137}Cs (km^2)			
		1-5 Ci/km^2	5-15 Ci/km^2	15-40 Ci/km^2	>40 Ci/km^2
Belgorod region	27.1	1,620	-	1,900	310
Bryansk region	34.9	6,680	2,700	-	-
Voronezh region	52.4	1,660	-	-	-
Kaluga region	29.9	3,400	1,350	-	-
Kursk region	29.8	1,350	-	-	-
Lipetsk region	24.1	1,630	-	-	-
Leningrad region	85.9	1,200	-	-	-
Nizhegorod region	74.8	85	-	-	-
Orel region	24.7	8,300	126	-	-
Penza region	43.2	3,900	-	--	-
Ryazan region	39.6	5,400	-	-	-
Saratov region	100.2	150	-	-	-
Smolensk region	49.8	84	-	-	-
Tambov region	34.3	480	-	-	-
Tula region	25.7	10,300	1,150	-	-
Ulyanovsk region	37.3	1,100	-	-	-
Mordovia republic	26.2	1,940	-	-	-
Tatarstan republic	68.0	170	-	-	-
Chuvash republic	18.0	60	-	-	-
Total		**49,509**	**5,326**	**1,900**	**310**

Table 10.3. Distribution of Russian population size according to density of soil contamination with ^{137}Cs.

Soil contamination density (Ci/km^2)	Population size (x 1,000)
>1	2,700
>5	338
>15	91

Table 10.4. Ratio of the average absorbed dose to the thyroid in children and teenagers to that of adults.

Type of Settlement	Age (years) by May 1, 1986					
	<1	1-2	3-6	7-11	12-17	>18
Urban	13 ± 3	9 ± 4	6 ± 2	2.5 ± 0.8	1.5 ± 1.0	1
Rural	5 ± 3	5 ± 2	3 ± 1	2.2 ± 1.0	3 ± 2	1

Table 10.5. Collective dose to the thyroid from the incorporated ^{131}I for residents of the most heavily contaminated territories in Russia.

Territory	Population Size (x 1,000,000)	Collective Dose (x 1,000 person-Gray)
Bryansk region (total)	1.5	60
Bryansk region (controlled areas)	0.11	22
Tula region	1.9	60
Orel region	0.9	15
Kaluga region	1.0	10
Total	5.3	145

Table 10.6. Average effective dose of internal irradiation of rural residents from Cs and Sr radionuclides ($\mu Sv/kBq/m^2$).

Time after Chernobyl Disaster	Type of Soil	
	Soddy-podzolic	Black earth
2 months	40	27
1 year	90	28
8 years	168	30
1995 to 2056	16	1
70 years	184	31

Table 10.7. Average effective external dose normalized to density of soil contamination with ^{137}Cs at various intervals after the Chernobyl disaster ($\mu Sv/kBq/m^2$).

Type of Settlement	First year	1986-1994	1986-2056	1995-2056
Urban	8	21	40	19
Rural	13	34	64	30

Table 10.8. The effective external dose which the population is expected to accumulate over 70 post-Chernobyl years (mSv).

Type of Residents	Density of soil contamination with ^{137}Cs (Ci/km^2)			
	1 15		**40**	**100**
Urban	1.84	27.6	73.6	184
Rural	2.37	35.5	94.7	237

Table 10.9. Average radiation load in some settlements of the Bryansk and Tula regions.

Settlement	Contaminant (MBq/m^2)		Dose to thyroid by age group (Gy)			Effective dose (mSv) over 1986-1994				Effective dose (mSv) over 1995-2056		
	^{137}Cs	^{90}Sr	<7	7-17	>17	γ	Cs	Sr	Σ	γ	Cs+Sr	Σ
Bryansk region:												
Novozybkov	0.7	0.02	0.4	0.15	0.04	14	5	0.02	19	13	8	21
Zaborye	4.3	0.04	1.2	0.7	0.3	98	19	0.3	117	130	60	190
Svyatsk	1.6	0.02	0.3	0.2	0.06	51	11	0.02	62	48	23	71
Tula region:												
Plavsk	0.5	0.01	0.4	0.07	0.05	10	1.5	0.02	12	8.9	0.3	9
Rakhmanov	0.4	-	0.4	0.3	0.1	12	2.0	0.03	14	10.4	0.6	11
Kamynino	0.3	-	0.4	0.3	0.1	9	1.8	0.03	11	7.9	0.5	8

Table 10.10. Radiation risk for some settlements of the Bryansk and Tula regions.

Settlement	^{137}Cs (MBq/m^2)	Effective dose(mSv) 1986-1994	Effective dose (mSv) 1994-2056	Effective dose(mSv) 1986-2056	Lifetime risk (%)	Average individual annual risk
Bryansk region:						
Novozybkov	0.7	19	21	40	0.28	4.1×10^{-5}
Zaborye	4.3	117	190	307	2.19	3.1 x 10-4
Svyatsk	1.6	62	71	133	0.95	1.4×10^{-4}
Tula region:						
Plavsk	0.5	12	9	21	0.15	2.1×10^{-5}
Rakhmanov	0.4	14	11	25	0.18	2.6×10^{-5}
Kamynino	0.3	11	8	19	0.14	1.9×10^{-5}

11.0: RADIATION RISK CONNECTED TO RADIOCHEMICAL PRODUCTION FACILITIES

11.1 INTRODUCTION

The development of strategic nuclear weapons, as well as a demand for nuclear power energy in general, required creation of many nuclear complexes, such as the Mayak nuclear complex (Chelyabinsk), the Siberian nuclear complex (Seversk, near Tomsk), and the Krasnoyarsk radiochemical complex (Krasnoyarsk). The local population has experienced the negative impact of these and other similar enterprises, primarily through the contamination of the atmosphere, water sources, and soil with radioactive industrial releases, especially at the earlier stages of operation of these plants. An additional hazard has been due to various accidents that occur at enterprises of this type.

11.2 THE MAYAK NUCLEAR COMPLEX (SOUTH URALS)

The Mayak Production Association is responsible for considerable radioactive contamination of some parts of the Chelyabinsk, Kurgan, and Sverdlovsk regions (1). The imperfect technologies, underestimation and lack of knowledge of perilous radiation effects on the population and environment, which were typical of the initial stages of the Mayak operation, sometimes led to unchecked releases of fission and activation products resulting in radiation exposures to the people living in the Mayak neighborhood (1). The highest environmental contaminations were related to: (1) discharges of liquid wastes into the Techa River in 1949-1956; (2) an explosion of the storage facility for highly radioactive liquid wastes in 1957 (the Kyshtym accident); and (3) gaseous aerosol releases in 1949-1957 (1). Below we examine only radiation risk assessments for the residents of the Techa River basin.

During 1949-1956, about 7.6 x 10^7 m3 of liquid wastes with a total radioactivity of 10^{17} Bq (2.75 x 10^6 Ci) were discharged into the Techa River (2-4). More than 124,000 people living along the Techa and Iset rivers received considerable external and internal doses. The highest exposures involved those 29,000 individuals who lived there in 1950-1952, when the discharges were particularly intensive. The greatest contaminants were ^{89,90}Sr and ^{137}Cs and the highest doses were accumulated in bone surface cells and the red bone marrow (2). The red bone marrow dose distribution among the exposed residents is shown in Table 11.1 (2). The highest individual doses were 3 to 4 Gy (2).

Calculations show that the individual annual risk of death from cancer is 1.4 x 10^{-3} for the irradiated population and 1.05 x 10^{-3} for controls at a 95% confidence interval of (1.31-1.50) x 10^{-3} and (1.01-1.09) x 10^{-3}, respectively (2). From here it follows that the individual annual risk of death specifically from radiation-induced cancer is about 3.5 x 10^{-4}. According to other data (5), the individual annual risk of cancer for residents of the Techa riverside near the settlement of Muslimovo in 1992-1995 was 1.8 x 10^{-4} when the use of water from the river was restricted and 7 x 10^{-4} when it was not (Table 11.2). If one assumes that radionuclide intake rates for humans within the next ten years are kept at the level of 1992-1995, the lifetime radiation risk will be from 3 x 10^{-3} to 1.2 x 10^{-2}. This is the highest estimate of radiation risk for Russia and other countries of the world as well (5).

11.3 THE SIBERIAN NUCLEAR COMPLEX

In building the plants of the Siberian nuclear complex, efforts were undertaken to correct the main errors in handling radioactive wastes characteristic of the initial years of the Mayak activity (6). This resulted in a healthier radiological situation for residents of nearby areas, in particular in the town of Seversk (Tomsk).

In 1995, the radiological situation in Seversk and the surrounding territories was determined by the global radiation background formed as a result of earlier nuclear tests and the operation of the Siberian nuclear complex. During this year there were no accidents involving radioactive substances at this complex (7). The radiological situation in the area around the nuclear complex, which depends on the release of radioactive substance into the atmosphere, was relatively stable, with the radiation levels corresponding to the natural radiation background rate (7-15 μR/hour). As shown by monitoring data, the content of ^{137}Cs and ^{90}Sr in the soil of the settlements in the 7 to 25 km zone around the nuclear complex was 30 to 100 mCi/km^2, which is close to the values of the global radiation background over the Russian Federation (7). In the north-east direction (downwind), at a distance of 8-13 km from the boundary of the protective "sanitary" zone around the Siberian nuclear complex, there are areas whose soil contamination with ^{137}Cs exceeds 2 or 3 times the global background. This situation is indeed due to radioactive releases of the nuclear complex for many years of operation, but these areas are uninhabited (7).

The annual radiation doses for residents of Seversk and the nearby settlements in 1994 and 1995 are given in Table 11.3 (7). One can see that the doses did not change. The higher internal doses for rural residents in comparison with those for Seversk residents are the result of an accident at the radiochemical plant of the nuclear complex in April 1993. At the time of the accident, the dose rate of gamma-radiation in the protective sanitary zone reached 300-600 μR/hour and in the nearest settlement in the direction of the radioactive trace (the village of Georgievka at a distance of 8 km from the sanitary zone) it was 20-45 μR/hour. The soil contamination density was 0.5-2.0 Ci/km^2. Calculations showed that the total effective dose for Georgievka residents could have been 0.01 rem for the first 10 days and 0.05 rem for the first post-accident year (6). The corresponding lifetime risk assessments (Table 11.4) were based on the data from Tables 11.3 and 9.3 and the assumption that the annual equivalent doses would remain at the level of 1995. The radiation risk values shown in Table 11.4 are very low. They demonstrate that under conditions of routine operation the Siberian nuclear complex does not represent a threat to the health of the nearby population.

In evaluating radiation risk during emergency situations one can use the data from Table 9.1. They show that a single dose of 1 mSv received in a radiation accident corresponds to a lifetime risk of death from radiation-induced cancer of 1.8×10^{-4}.

11.4 THE KRASNOYARSK RADIOCHEMICAL COMPLEX

The designers of the Krasnoyarsk radiochemical complex were able to remove many of the shortcomings of the earlier-built analogous plants (6), which surely had a positive impact on the radiological situation in the vicinity of the complex (6). Over the whole period of the Krasnoyarsk complex operation, its atmospheric releases have not exceeded the adopted maximum permissible levels and have been lower than at the other radiochemical plants. No accidents that would be

responsible for heavy environmental radioactive pollution were recorded over the operational lifetime of the complex (6).

For more than 30 years, however, the weakly radioactive liquid wastes from the Krasnoyarsk complex have been discharged into the Enisey River. The prevailing radionuclides in the wastes are ^{24}Na, ^{56}Mn, and ^{32}P (6). The radiation doses from the incorporated radionuclides to the population of the Enisey riverside are about 4 mSv/year for the bone tissue and 1 mSv/year for the whole body (6).

The impact of the Krasnoyarsk radiochemical complex on the radioecological condition of the Enisey River was evaluated in reference 8. The maximum effective equivalent dose from consumption of 1 kg of fish from the Enisey River was 50 μSv, mainly on account of ^{32}P. An average dose per kilogram of fish was from 10 μSv at a distance less than 250 km from the place of discharge of radioactive liquid wastes to no more than 0.6 μSv at much larger distances along the radioactive trace. With an individual annual consumption of 20 kg of river fish, the radiation dose does not exceed 0.5-1.0 mSv, which is below the established dose limit. If river fish consumption increases to 100 kg/year, which can be the case with local fishermen and their families, the maximum annual dose ranges from 1 to 5 mSv. So fishermen and their families may be considered a critical population group in the Enisey basin. For people consuming river fish at a distance of up to 250 km from the point of radioactive waste discharge the average annual risk of cancer is 10^{-5}, whereas for fishermen and their families it may reach 10^{-4}. Much farther from the place of waste discharge the fish consumption-related risk is 10^{-6} to 10^{-7}, which is much lower than the risk from the natural radiation background (8).

11.5 CONCLUSIONS

The above-given data on radiation risk for people living in areas close to nuclear plants cannot claim to be very full. Our intention was to illustrate risk levels corresponding to the current status of radiation safety of the population. A separate detailed consideration is required for radiation risk related to possible radiation accidents at nuclear plants and storage facilities for radioactive wastes.

Table 11.1. Distribution of absorbed doses to the red bone marrow (RBM) among the people living on the banks of the Techa River.

% of Population	RBM dose, Gy
11	<0.1
27	0.10 - 0.20
27	0.20 - 0.35
9	0.35 - 0.50
18	0.50 - 1.0
8	>1.0

Table 11.2. Risk of radiation-induced cancer from water use from the Techa River basin near the Muslimovo settlement in 1992-1995.

Radionuclide	Estimates assuming unrestricted water use	Estimates assuming water use restrictions
^{90}Sr	$(4.5 \pm 1.2) \times 10^{-5}$ [11.5×10^{-5}]	$(2.1 \pm 0.5) \times 10^{-5}$ [5×10^{-5}]
^{137}Cs	$(8.5 \pm 2.0) \times 10^{-5}$ [58×10^{-5}]	$(2.4 \pm 0.5) \times 10^{-5}$ [13×10^{-5}]
$^{239,240}Pu$	$(1.3 \pm 0.7) \times 10^{-7}$ [3.3×10^{-7}]	$(1.0 \pm 0.5) \times 10^{-7}$ [3×10^{-7}]
Total	$(13 \pm 3) \times 10^{-5}$ [70×10^{-5}]	$(4.5 \pm 1.0) \times 10^{-5}$ [18×10^{-5}]

Note: Maximal risk values are indicated in the square brackets.

Table 11.3. The annual equivalent doses to the population in 1995 (mrem/year).

Type of Radiation	Seversk	Samus settlement	Orlovka village
External	7.78	0.01	0.01
Internal	0.02	16.5	4.5
Total	7.8	16.5	4.51

Table 11.4. Lifetime risk of death from radiation-induced cancer for residents of the town of Seversk and the surrounding countryside.

	Seversk	Samus	Orlovka
Risk of Death	4×10^{-4}	8×10^{-4}	2×10^{-4}

12.0: RADIATION RISK RESULTING FROM NUCLEAR TESTS AT THE SEMIPALATINSK TEST SITE

12.1 INTRODUCTION

Between 1949 and 1962, 118 nuclear tests (including 25 ground and 88 atmospheric explosions) were performed at the Semipalatinsk Nuclear Test Site (1). The nuclear explosions responsible for very heavy environmental contamination included the four ground explosions of August 29, 1949; September 24, 1951; August 12, 1953; and August 24, 1956 (1). The unfavorable meteorological conditions (strong winds up to 75 km/hour and heavy rains) during the first USSR nuclear test of August 29, 1949 brought about a radioactive contamination of regions far away from the Semipalatinsk Test Site (STS). (1)

Specialists believe that the above-mentioned four explosions formed 95% of the total collective dose in the affected regions outside the STS (1). This primarily applies to the Altai Territory (2-4). The principal contribution to the population exposure came from the first Soviet nuclear explosion of August 29, 1949.

12.2 IRRADIATION OF THE ALTAI TERRITORY RESIDENTS RESULTING FROM SEMIPALATINSK NUCLEAR TESTS

The Altai Territory is located along the most probable direction of the wind from the STS. The minimal distance from the test site to the boundaries of the Altai Territory is 150 km. A reconstruction of the radiological situation in the Altai Territory in the years the nuclear explosions were performed made it possible to evaluate the collective effective doses to the population from radioactive products of the explosions. For 1949, this dose was 32,000 person-sievert. The total collective dose from other nuclear explosions was about 10,000 person-sievert, including 3,000 person-sievert from the explosion of August 7, 1962 (2).

The internal dose from ingestion of foodstuffs from the contaminated ecosystem adds to the external dose from 15 to 120% depending on the season of radionuclide fallout. About 75% of the dose builds up within the first one to five days and about 95% accumulates within the first 15 to 30 days from the onset of time of fallout. Therefore, the impact of nuclear test fallouts in the first approximation can be regarded as similar to a single acute exposure combined with a weaker, subacute, exposure extending over one year (2).

Among the nuclides responsible for the internal dose, particularly important are the short-lived isotopes ^{131}I and ^{106}Ru. Jointly they produce about 70% of the effective internal dose (2).

For residents of 44 settlements of the nine regions of the Altai Territory, the reconstructed dose from the nuclear explosion of 1949 exceeds 0.25 Sv/year (2). In view of the high levels of radiation exposure of the Altai population due to the 1949 explosion, we examine in more detail how the effective dose from this explosion was made up. The data from reference 4 refer to a certain

representative point located in the Altai Territory at a distance of 236 km from the explosion epicenter on the axis of the radioactive trace. The gamma-radiation dose rate in air, normalized to a time of three hours post-explosion, was 4.35 R/hour. The time during which the radioactive cloud passed over the representative point was estimated to be 2.66 hours. The absorbed gamma-radiation dose in air accumulated over the period from the time of radioactive fallout to the time of complete decay of the radioactive substances was 44.7 rad. The effective external dose accumulated over 50 years of living in the contaminated zone was 41 rem. The time course of dose buildup was as follows: 35% of the total dose accumulated in the first 24 hours, 79% in the first month, 97% in the first year, and 98% in the first 5 years. The densities of soil contamination by the principal dose-forming radionuclides normalized to the time of nuclear explosion are shown in Table 12.1. The calculated effective internal dose was 16.5 rem, which implies a total effective internal plus external dose of about 58 rem. Relative contributions of individual radionuclides to the total effective internal dose are given in table 12.2, where the inhalation and peroral pathways of radionuclide accumulation in the organism are indicated.

The absorbed doses to various critical organs of the body due to incorporated radionuclides after the nuclear explosion of 1949 are shown in Table 12.3. Calculations have shown that after the explosion of 1949, even a short-time residence in the affected territories resulted in high doses due to the decay of the incorporated radionuclides. How the calculated effective internal dose in such part-time residents depends on the time of living on the contaminated land over the period of 50 post-explosion years (in % of the dose that would accumulate after living there during all these 50 years) is demonstrated in Table 12.4. With external exposure, the time of dose accumulation is equal to the time of living on the contaminated land. With internal exposure, the dose buildup from the incorporated radionuclides continues even outside the contaminated area. This is illustrated in Table 12.4.

Analysis of the above data suggests the following conclusions regarding the impact of the nuclear explosion of 1949:

(1) The highest contribution (about 42%) to the internal dose comes from ^{131}I (see Table 12.2) ingested primarily with milk. The highest absorbed internal doses are found in the thyroid (282 rad) (see Table 12.3). Together with the external dose, the total dose to the thyroid is about 320 rad. In one of the Altai Territory region, maximal absorbed doses to the thyroid after the explosion of 1949 reached 830 rad.

(2) The external dose is accumulated within a rather short time: about 50% of the total external dose builds up within the first 4 days after the fallout and 96% of the dose accumulates within the first year. The accumulation of the internal dose proceeds more slowly: no less than 40% of the total effective internal dose accumulates within the first post-explosion month and no less than 75% within the first three years. Jointly the external and internal exposures give about 70% of the total effective dose within the first month of living in the contaminated area. Therefore, the people who lived in areas contaminated as a result of the nuclear explosion of 1949 were in fact subjected to acute irradiation.

For an individual who lived in the contaminated area of the Altai Territory during the explosion of 1949 and for the first post-explosion year, the total accumulated dose within the next 50 years of life will reach 96% of the dose this individual would have received if he had lived all 50 years in this area. This conclusion is very important in assessing radiation risk for non-permanent residents of the

affected areas.

Unfortunately, there are large uncertainties in the soil contamination density distribution over particular settlements of the Altai Territory. These uncertainties interfere with the reconstruction of a complete and accurate picture of the conditions of external and internal exposure after various nuclear explosions. Additional difficulties refer to recording doses for the population during the passage of the radioactive cloud over a particular place. Little is known about daily exposure profiles, diets, etc., for different age, sex, and professional groups in the contaminated areas. The overall outcome of all these uncertainties is that we know only approximate average radiation doses for residents of the Altai Territory settlements. So far no accurate reconstruction of the dose distribution among the Altai population has been made. This circumstance imposes serious limitations on the possibility of radiation risk assessment for the Altai residents (5).

12.3 ASSESSMENT OF RADIATION RISK FROM NUCLEAR TESTS FOR THE GENERAL PUBLIC

The conclusion drawn in the previous section to the effect that the exposure to fallout from nuclear explosions corresponds to the conditions of acute irradiation makes it possible to use the data from Table 9.1 to calculate the maximal radiation risk for residents of the Altai Territory, as these data contain estimates of risk from a single acute exposure at age zero in Russia. It is well known that risk parameters (lifetime probability of death from radiation-induced cancer and reduction of life expectancy) strongly depend on the age at exposure. These parameters are relatively large for children and teenagers (0-20 years) and rapidly diminish toward older ages. According to data from rural residents of the Altai Territory (6), the lifetime risk of death from radiation-induced cancer for children irradiated at an age below 10 years is about twice as high as for men irradiated at 35 and nearly three times as high as for women irradiated at 35 (Table 12.5).

Table 12.5 gives risk estimates for exposure at age zero to different single radiation doses. These values should be regarded as maximal since exposure at age zero produces maximal effects.

Of interest is the time course of manifestations of late health effects related to nuclear tests. This subject was studied in detail in reference 6, where radiation risk for residents of the Altai Territory after the nuclear tests at the Semipalatinsk Test Site was estimated. Data on the exposed population age structure in 1949 and on the age- and sex-specific mortality from spontaneous cancers in the Altai Territory in 1989 were reported. About 20,000 residents of the Uglovsk and Rubtsovsk regions (belonging to the highest-risk zone) which had received relatively high doses (0.8 Sv on the average) from the first nuclear explosion of 1949 were studied. Risk was calculated separately for males and females and summarized in Tables 12.6 and 12.7 (6). These tables show estimates of radiation-induced mortality summated over time: the expected total number of deaths, their number prior to 1994 and the expected number after 1994. In Table 12.7, the calculated data refer to people exposed to radiation and fallout from the 1949 explosion at the age of 0-20 who survived to 1994, i.e., to the age of 45-65.

All additional deaths from radiation-induced leukemia have already occurred within about 25 years after the nuclear explosion of 1949. Most of the "solid" radiation-induced cancers are going to occur in the future - after 1994. The mortality from radiation-induced cancers will exceed that from

spontaneous cancers by a factor of 2 for women and by a factor of 1.6 for men.

For the population of all ages, half of the additional deaths from the radiation-induced cancers have already happened prior to 1994 (Table 12.6). The rest of these cancers will manifest themselves after 1994. Naturally, different cancer types have different manifestation time profiles. The maxima of annual additional mortality from radiation-induced cancers fall into the 5-10 year interval post-explosion for leukemia and into the 50-55 year interval post-explosion for gastrointestinal and other cancers. More information in this respect is shown in Table 12.8 (6).

Thus, the data concerning the population of the Altai Territory zone most gravely affected by the nuclear explosion of 1949 show that the total lifetime radiation risk is somewhat higher than 1.0×10^{-1} for men and 8.8×10^{-2} for women (see Table 12.6). The maximum radiation risk for the same conditions (exposure at age zero) is 1.4×10^{-1} (see Table 12.5).

12.4 CONCLUSIONS

The main contribution to the radiation exposure of the Altai Territory was made by the first Soviet nuclear explosion of August 1949; therefore the radiation risk assessment was made only for this particular explosion. The highest-risk regions of the Altai Territory were studied.

For the most heavily affected population group, the risk of radiation-induced cancer over the level of spontaneous cancer of the same type is very high: from several tens of percent for most "solid" cancers and 100% for leukemia. Effective social and medical countermeasures are a prime necessity for this population group.

Table 12.1. The densities of soil contamination with predominant radionuclides after the 1949 nuclear explosion.

No	Nuclide	Contamination Density (Ci/km2)
1	Sr-89	19.8
2	Sr-90	0.16
3	Zr-95	99.8
4	Ru-106	11.1
5	I-131	468.0
6	I-133	5940.0
7	Cs-137	0.33
8	Ba-140	317.0
9	Ce-144	16.5
10	Pu-239	0.090

Table 12.2. The contributions of individual radionuclides to the effective internal dose after the 1949 nuclear explosion (%).

Radionuclide	Inhalation pathway	Peroral pathway
^{89}Sr	<0.1	2.4
^{90}Sr	<0.1	7.2
^{95}Zr	0.1	<0.1
^{106}Ru	0.5	32.8
^{131}I	0.3	42.4
^{133}I	0.3	2
^{137}Cs	<0.1	4.4
^{140}Ba	<0.1	1.4
^{144}Ce	0.5	0.2
^{239}Pu	5.6	<0.1

Table 12.3. The absorbed doses to various organs of the human body related to the nuclear explosion of 1949.

Organ	Dose (rad)	Organ	Dose (rad)
Urinary bladder	2.0	Skeleton	11.6
Stomach	3.7	Yellow bone marrow	13.2
Small intestine	5.6	Red bone marrow	7.0
Upper large intestine	23.1	Skin	1.8
Lower large intestine	65.9	Spleen	2.0
Kidney	2.0	Testis	1.9
Liver	2.1	Dental fillings	2.0
Lung	3.6	Thyroid	282.2
Ovary	2.2	Uterus	2.1
Pancreas	2.0	Other organs	1.9

Table 12.4. Dependence of the effective internal dose on the time of residence in the contaminated land after the explosion of 1949 (in % of that dose for full-time residents).

Time of Residence (years)	1	2	3	4	5	6	7	8	9	10
Dose (%)	96.9	97.5	97.9	98.3	98.7	98.9	99.2	99.4	99.6	99.7

Table 12.5. Maximum lifetime risk of death from radiation-induced cancer as a function of dose of a single exposure at zero age.

Risk Parameter	Dose (rem)					
	20	35	40	50	80	100
Lifetime risk	3.4×10^{-2}	6.0×10^{-2}	6.8×10^{-2}	8.6×10^{-2}	14×10^{-2}	17×10^{-2}

Table 12.6. Lethal cancers in residents affected by the nuclear explosion of 1949 (the number of lethal spontaneous cancers for the same population is indicated in parentheses).

Type or Localization of Cancer	Number of expected radiation-induced cancers (per 10,000 individuals)		Additional Cancer Deaths prior to 1994 (%)	
	Males	Females	Males	Females
Leukemia	150 (42)	90 (24)	100 (58)	100 (64)
Respiratory organs	240 (700)	70 (100)	74 (56)	77 (57)
Mammary glands	-	50 (100)	-	73 (59)
Gastrointestinal organs	410 (600)	410 (410)	36 (55)	33 (55)
Other organs	210 (250)	250 (340)	34 (53)	39 (57)
Thyroid	10	6	75	69
Total	1020 (1,600)	876 (1,000)	54 (55)	48 (57)

Table 12.7. Expected lethal cancers in the population affected by the nuclear explosion of 1949 (the total number of future cancer deaths per 10,000 persons alive in 1994).

Type or Localization of Cancer	Radiation-induced		Spontaneous	
	Males	Females	Males	Females
Leukemia	0	0	50	20
Respiratory organs	120	30	840	100
Mammary glands	-	30	0	90
Gastrointestinal organs	640	630	730	400
Other organs	340	370	300	300
Thyroid	7	4	-	-
Total	1,000	1,050	1920	910

Table 12.8. Time of maximum annual additional mortality from various radiation-induced cancers for the population of all ages affected by the nuclear explosion of 1949.

Type or Localization of Cancer	Time post-explosion (years)	
	Males	Females
Leukemia	5-10	10-15
Respiratory organs	15-20	15-20
Mammary gland	-	30-35
Gastrointestinal organs	45-50	50-55
Other organs	50-55	50-55
Thyroid	10-15	10-15

13.0: ASSESSMENT OF RADIATION RISK WITH ALLOWANCE FOR DOSE AND RADIOSENSITIVITY DISTRIBUTIONS

13.1 INTRODUCTION

Conventional methods of risk assessment do not always allow the damage to the public from exposure to radiation to be adequately estimated because of two main reasons. First, these methods usually operate with average values of radiation dose, which in many cases may lead to underestimation of risk. Second, use is made of an average probability of a health effect corresponding to a unit radiation dose; therefore the variability of radiosensitivity among a population is ignored. With high doses this will not lead to significant errors. However, in low and moderate dose ranges, this approach yields underestimated risk values.

Our approach to radiation risk assessment (1-3) has been based on experimental studies demonstrating that mammalian and other biological populations have a comparatively small fraction of individuals (from 5 to 12%) which show a so-called hypersensitivity to radiation. This finding justifies the conclusion that it is the radiosensitivity variability among a mammalian population that underlies the observed inadequacy of extrapolations from the effects of high doses to those of moderate and low doses. Indeed, at high doses and dose rates of acute and chronic radiation exposures, the hypersensitive individuals can only insignificantly affect the general picture of radiation damage to the population as a whole. This is due to the relatively small share of hyperradiosensitive individuals in a population and also to the fact that their death would differ from that of others only in time of onset. In other words, with high radiation exposures, the health effect depends on non-hyperradiosensitive individuals. With lower radiation exposures, only hyperradiosensitive individuals, in contrast to others (especially to radioresistant ones), will show health effects. These could be manifested at the organ level or the organism as a whole, and also at the population level.

The experimental data that have been accumulated in regions of Russia contaminated after the Chernobyl disaster or nuclear weapon tests suggest the following important conclusion: moderate and low radiation doses and dose rates have much more pronounced health effects than could have been expected on the basis of extrapolation from high doses to low ones (2).

There is, therefore, a need for a new approach to radiation risk assessment which would take into consideration the variability of individual radiosensitivity in a biological population. Such an approach is described below (1-4).

13.2 MATHEMATICAL MODEL OF RISK OF DEATH ALLOWING FOR DOSE AND RADIOSENSITIVITY DISTRIBUTIONS

We consider an irradiated population whose size is sufficiently large to use continuous distributions of radiation dose and radiosensitivity among its members. Let us introduce a probability density of population distribution according to radiation dose $dp(D)/dD$ and cumulative probability $F(D)$ of a radiobiological effect. Then the increment of radiation risk, i.e., the risk of this radiobiological effect, in the dose range from D to D+dD is

$$dR = dp(D)/dD \times F(D) \times dD$$

To obtain the radiation risk values for the population studied, one has to integrate the risk increment dD over all possible dose values for the population. Thus we have:

$$R = \int_0^{\infty} dR = \int_0^{\infty} dp(D)/dD^{*}F(D)^{*}\, dD \tag{1}$$

Thus, with the approach we propose, the radiation risk is calculated as the product of the probability density of receiving a certain dose by the cumulative probability of realization of a radiobiological effect at this dose, the product being then integrated over all dose values from zero to infinity. In fact, a rigorous theoretical approach to risk assessment is proposed. The only assumption used here is that the size of the population to be studied is not too small.

13.3 MODEL DESCRIPTION OF DOSE DISTRIBUTION AMONG A POPULATION

The probability density of population distribution over the radiation dose in a radioactively contaminated area is ordinarily well described by a log-normal distribution (4, 5):

$$\frac{dp(D)}{dD} = \frac{\lg e}{\left(\sqrt{2\pi}\right)\cdot S \cdot D} \exp\left[-\frac{\lg^2 (D/A)}{2 \cdot S^2}\right] \tag{2}$$

In this expression, A and S are the parameters of the log-normal distribution related to the mean dose D_l for this distribution and to the mean-square deviation σ_l by the formulas:

$$S = \left[\ln\left(1 + K_l^2\right)\right]^{1/2} \cdot \lg e \tag{3}$$

$$A = D_l / \left(1 + K_l\right) \tag{4}$$

where $K_l = \sigma_l/D_l$ is the variation coefficient for a log-normal distribution. Thus, to describe a log-normal distribution it is sufficient to know the mean dose D_l and the variation coefficient K_l . By varying K_l and D_l values, we can obtain a model description of any distribution of radiation dose in a population.

13.4 MODEL DESCRIPTION OF INDIVIDUAL RADIOSENSITIVITY

In order to define the form of the function F = F(D) in expression (1), we used the mathematical model of radiation-induced mortality for a nonhomogeneous population from Reference 2. The

model is based on the assumption of non-uniform individual radiosensitivity of critical system cells. Accordingly, the distribution of individuals in the radiosensitivity index is described by a continuous function. An important component of the mortality model is an adequate approximation of the continuous function by a discrete function. This transition from a continuous distribution to a discrete one is equivalent to the representation of the initial nonhomogeneous population as a set of a finite number of homogeneous subpopulations. The radiosensitivity index of the critical system cells in individuals of each homogeneous subpopulation and also the number of these individuals are uniquely determined by the initial continuous distribution. Other important components of the model are the formulas used to express the biometric functions describing the mortality dynamics of the nonhomogeneous population through the biometric functions defining the mortality dynamics of the constituent homogeneous subpopulations.

To calculate the radiation-induced mortality dynamics of the subpopulations, use was made of the mathematical model of mortality dynamics for homogeneous populations and the mathematical models of critical systems (2), which formed parts of the model of radiation-induced mortality for the nonhomogeneous population. The resulting structure of the model reflects the actually existing levels of manifestation of adverse radiation effects. The first level is that of a critical system, whose radiation injury is largely determined by the radiosensitivity of the constituent cells. The second level is that of the whole organism. Here the probable outcome of irradiation depends mainly on the extent of radiation injury of the respective critical system, i.e., on the individual cell radiosensitivity of the system. The third level is that of the population, which includes individuals with differing individual radiosensitivities of the critical system cells. Modeling results also support our hypothesis that the reason for the more pronounced radiobiological effects in the Chernobyl disaster zone than could be expected is the variability of individual radiosensitivity in a population. For instance, the model shows that consideration for the normal and log-normal distributions of individuals in the radiosensitivity index of the critical system precursor cells results in reproducing higher rates of radiation-induced mortality and lower survival than could have been predicted from the average radiosensitivity indices alone. Differences in prediction are more pronounced with greater scatter in individual radiosensitivity indices of the respective critical system precursor cells in a nonhomogeneous population. These differences are greatest when the distribution of the individuals in the nonhomogeneous population is log-normal with a high variance.

Earlier we reported (2) that the collected clinical data demonstrated the health effects of exposure to radiation. Some of the data were collected during the course of examination of several groups of patients that had undergone medical treatment with ionizing radiation. The patients of each group had the same type of health problem and received the same radiation treatment. Analysis of the data showed a broad variability of radiosensitivity both at the organism level and at the level of the corresponding critical system (e.g., the central nervous system when the head was irradiated). It should be noted that the percentage of individuals with increased radiosensitivity was rather similar among different groups of patients: 10% to 20%. The number of radioresistant patients varied from 14% to 20%. Also summarized were clinical data on persons ("liquidators") directly involved in the remediation of the Chernobyl disaster's aftereffects (2). These data are particularly valuable because they characterize the response to low radiation doses (0.002 - 0.2 Gy) of large groups (cohorts) of healthy people. Each cohort included persons of approximately the same age performing similar jobs for more or less similar lengths of time. So the total radiation dose for most individuals in a cohort was roughly the same. Moreover, the contributions of all other nonradiation factors were also similar.

Analysis of the whole body of collected clinical data reveals considerable individual variability of radiosensitivity in all the cohorts examined: adverse health effects were found only in some of the liquidators and were related to a deficiency or a disease of a particular organ, tissue, or vital system (2).

Grouping the data according to total doses (low and moderate) revealed that there were hyperradiosensitive and radioresistant individuals in the studied cohorts. For instance, in cohorts of the liquidators whose total dose was not high (below 0.2 Gy), the percentage of persons who developed a chronic disease after 1986 (the year of the Chernobyl disaster) ranges from 4% to 25%. At higher total doses (0.2 - 0.68 Gy), the percentage of persons that remained practically healthy for 5 years after the disaster was 8%. These results are consistent with foregoing estimates of the percentages of radiosensitive and radioresistant individuals. Thus, the results of the analysis of clinical observations of irradiated people (2) support the validity of basic concepts underlying the model of radiation-induced mortality and also emphasize their importance in modeling the effects of radiation on the population.

Quite significant was the finding that 10% to 20% of individuals have enhanced radiosensitivity (2), which is nearly twice as much as was thought earlier. It relates to the above-mentioned conclusion, drawn from the study of a model of mortality of a nonhomogeneous population, that even very low radiation can have fatal consequences for individuals who have hyperradiosensitive critical system precursor cells. This modeling result suggests that a new strategy of radiation protection must be adopted for the population in areas with an elevated radiation background: identification of and priority for hyperradiosensitive individuals when applying the whole set of preventive and protective measures, including moving them to noncontaminated places of residence.

13.5 ANALYSIS OF RISK DEPENDENCE ON THE DOSE DISTRIBUTION AND RADIOSENSITIVITY PARAMETERS

In this section we have used a normal distribution of radiosensitivity which is characterized by a mathematical expectation D_n (equal to the mean dose) and by a coefficient of variation K_n (equal to the ratio of the mean-square deviation to the mean dose). The mathematical expectation D_n for various radiobiological effects can be equated to the mean symptom dose SD_{50} or (in the case of lethal outcomes) to the mean lethal dose LD_{50}. The mean symptom doses for various radiobiological effects of acute irradiation are listed in Table 13.1 (4). The same table also shows doses corresponding to the risk levels of 0.1 and 0.9 for various health effects, as well as coefficients of variation and mean-square deviations. With acute irradiation, the mean-square doses range from 1 to 20 Gy and the variation coefficients from 0.18 to 0.83.

Table 13.2 gives the radiation risk values, calculated by formula (1) for cases of acute irradiation, for various mean doses of the log-normal dose distribution among the exposed population in the range 1 to 30 Gy for the K_n values of 0.1 and 1.0. Three radiobiological effects were considered: (1) loss of appetite (D_n= 1.0 Gy, K_n = 0.83); (2) vomiting (D_n = 2.20 Gy, K_n = 0.57); (3) death (D_n = 2.80 Gy, K_n = 0.18). For prodromal effects, there is a very weak risk dependence on the coefficient of variation K_n of the log-normal distribution, especially in the region of low doses D_1. For a lethal effect, the picture is quite different: risk is very strongly dependent on the coefficient of variation K_n.

The radiation risk dependence on the mean dose D_l of the log-normal distribution is illustrated in Figure 13.1 for the two prodromal effects and in Figure 13.2 for the lethal effect. One can see that the risk of prodromal effects is practically independent of the coefficient of variation K_n in the D_l range up to 0.30 Gy and is only determined by the mean dose of the log-normal distribution. By contrast, to assess the risk of lethal effect, one must know not only D_l but also K_n, since its dependence on the latter is quite strong (see Figure 13.2).

13.6 TABULATED RISK FUNCTION

The approach we propose can be used in studying the radiation risk for the population. Here two situations are possible. In the first situation, one deals with a real radiation exposure due to actual contamination of particular areas, water reservoirs, rivers, etc. In this case, the so-called real risk should be found and, as was shown below, the dose distribution among the population should be known. The second situation arises when the radiation risk to be estimated is related to possible future accidents at an industrial or other potentially hazardous enterprise. In this case, one estimates the probability of accidents of differing impacts, for which sets of possible dose distributions among the public must be found. This is a so-called potential risk.

The risk calculation procedure was the same for the two cases. Use was made of equation (1). To make such calculations easier, we tabulated the risk function $R = R(D_n, D_l, K_n, K_l)$ using equation (1). The tabulated risk function values are given in reference 6. There the dose D_n varies from 0.50 Gy to 2.50 Gy with a step of 0.25 Gy and from 2.50 Gy to 4.00 Gy with a step of 0.50 Gy. The dose D_l varies from 0.01 to 1.00 Gy. The coefficient of variation K_n varies from 0.1 to 1.0, and the K_l varies from 01. to 2.5. The calculation was performed for the risk range from 10^{-9} to 1.0. Some of the results are given in the Supplement to this section.

13.7 CONCLUSIONS

An adequate mathematical model of risk with consideration for the dose and radiosensitivity distributions among the irradiated population is proposed. A single assumption was used in the model: the population is large enough to allow continuous distributions of the dose and radiosensitivity among the individuals to be used. The dose distribution in the population is adequately described by a log-normal law. Both a normal and a log-normal law can be used to describe the distribution of radiosensitivity. The proposed approach can be employed in assessing real and potential risks of adverse health effects after acute radiation exposure. To simplify the calculations, we recommend that a tabulated risk function be used which depends on two variables (the mean dose of the log-normal distribution and the mean symptom dose of acute irradiation) and two parameters (the coefficients of variation of the normal and log-normal distributions).

Table 13.1. The mean symptom doses and doses of corresponding risk for various radiobiological effects of acute irradiation (Gray).

Radiobiological Effect	**Dose (Gy) of corresponding risk**			**Mean square deviation σ_n** (Gy)	**Coefficient of variation K_n**
	0.1	**0.5**	**0.9**		
	SD_{10}	**SD_{50}**	**SD_{90}**		
Erythema	4	5.8	7.5	1.22	0.21
Skin peeling	14	20	26	4.69	0.23
Loss of appetite	0.4	1.0	2.4	0.83	0.83
Nausea	0.5	1.7	3.2	1.05	0.62
Vomiting	0.6	2.2	3.8	1.25	0.57
Diarrhea	0.9	2.4	3.9	1.17	0.49
Death	2.2	2.8	3.5	0.51	0.18

Table 13.2. The radiation risk for some radiobiological effects of acute irradiation.

D_l, Gy	**Loss of appetite D_n=1.00 Gy; K_n =0.83**		**Vomiting D_n = 2.20 Gy; K_n = 0.57**		**Death D_n = 2.80 Gy; K_n = 0.18**	
	K_l=0.1	**K_l = 1**	**K_l = 0.1**	**K_l =1**	**K_l = 0.1**	**K_l = 1**
0.01	0.232×10^{-2}	0.234×10^{-2}	0.682×10^{-3}	0.686×10^{-3}	0.165×10^{-8}	0.177×10^{-8}
0.02	0.470×10^{-2}	0.477×10^{-2}	0.138×10^{-2}	0.140×10^{-2}	0.351×10^{-8}	0.472×10^{-8}
0.04	0.956×10^{-2}	0.984×10^{-2}	0.280×10^{-2}	0.289×10^{-2}	0.790×10^{-8}	0.680×10^{-8}
0.06	0.146×10^{-1}	0.152×10^{-1}	0.427×10^{-2}	0.446×10^{-2}	0.134×10^{-7}	0.658×10^{-6}
0.08	0.198×10^{-1}	0.208×10^{-1}	0.580×10^{-2}	0.613×10^{-2}	0.203×10^{-7}	0.319×10^{-5}
0.10	0.250×10^{-1}	0.266×10^{-1}	0.733×10^{-2}	0.789×10^{-2}	0.287×10^{-7}	0.103×10^{-4}
0.125	0.316×10^{-1}	0.342×10^{-1}	0.928×10^{-1}	0.102×10^{-1}	0.421×10^{-7}	0.313×10^{-4}
0.15	0.388×10^{-1}	0.421×10^{-1}	0.114×10^{-1}	0.127×10^{-1}	0.600×10^{-7}	0.745×10^{-4}
0.175	0.460×10^{-1}	0.503×10^{-1}	0.135×10^{-1}	0.154×10^{-1}	0.831×10^{-7}	0.150×10^{-3}
0.20	0.535×10^{-1}	0.588×10^{-1}	0.157×10^{-1}	0.181×10^{-1}	0.113×10^{-6}	0.269×10^{-3}
0.25	0.691×10^{-1}	0.762×10^{-1}	0.203×10^{-1}	0.242×10^{-1}	0.204×10^{-6}	0.681×10^{-3}
0.30	0.855×10^{-1}	0.942×10^{-1}	0.252×10^{-1}	0.308×10^{-1}	0.355×10^{-6}	0.139×10^{-2}

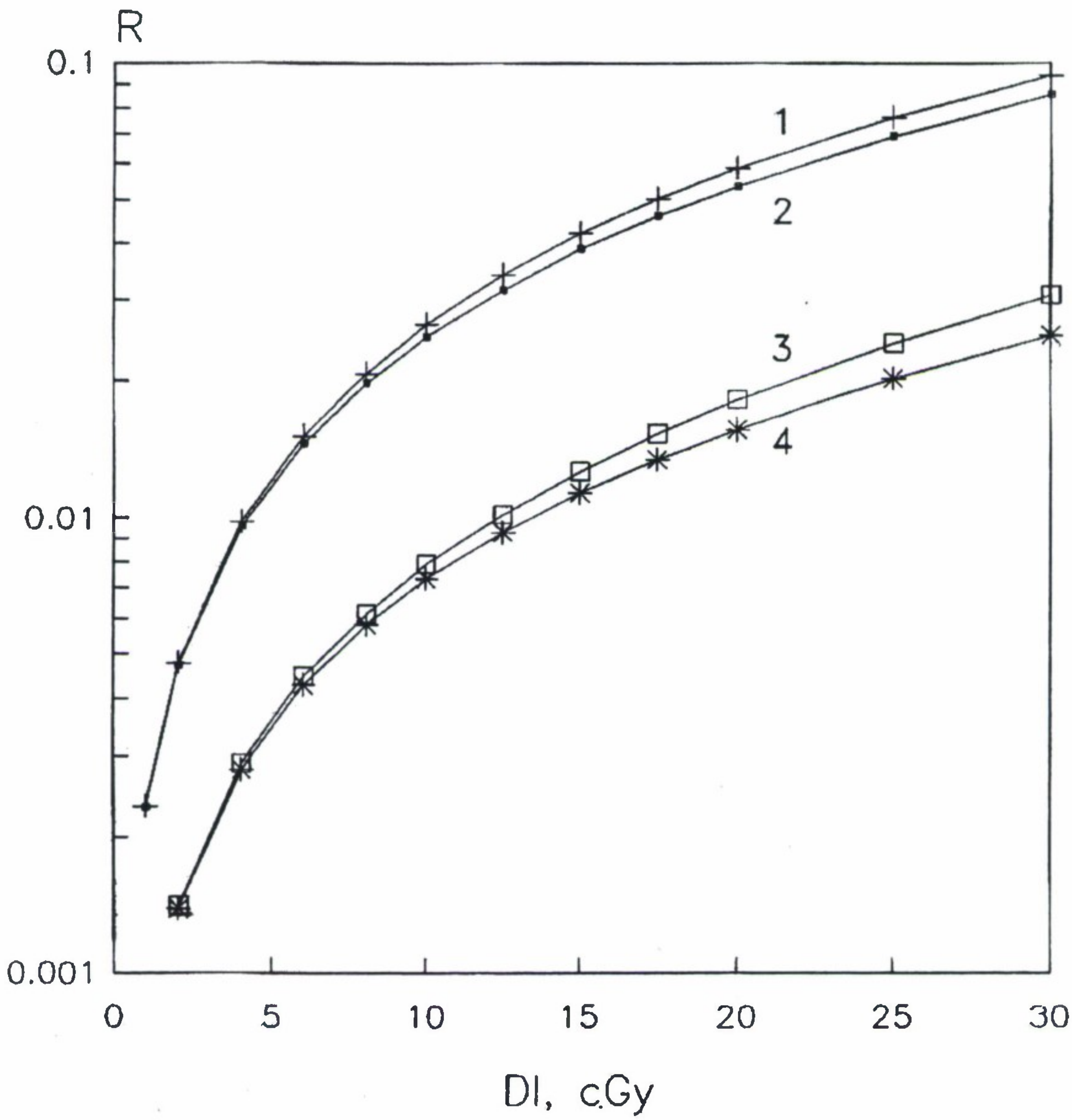

Fig. 13.1

Figure 13.1. The radiation risk dependence on the mean dose D_l of the log-normal distribution for two prodromal effects - loss of appetite (curve 1: $K_l = 1$; curve 2: $K_l = 0.1$) - vomiting (curve 3: $K_l = 1$; curve 4: $K_l = 0.1$).

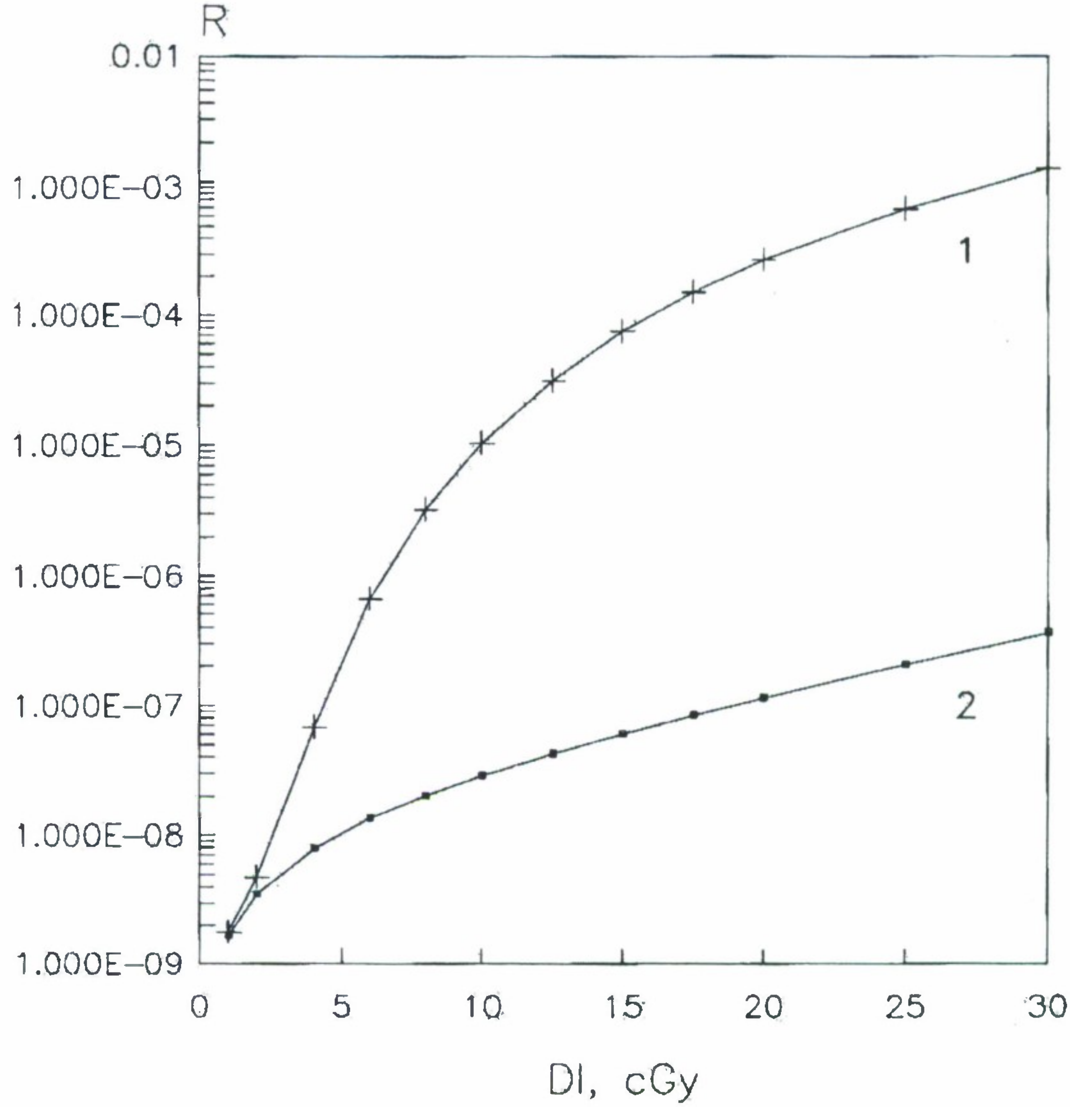

Fig. 13.2

Figure 13.2. The radiation risk dependence on the mean dose D_l of the log-normal distribution for lethal effect (curve 1: $K_l = 1$; curve 2: $K_l = 0.1$).

SUPPLEMENT

Tabulated Risk Function:

$$R = R\,(D_n, D_l, K_n, K_l)$$

D_n is the mean symptom dose SD_{50} of a normal distribution of radiosensitivity in a population.
D_l is the mean dose of a log-normal dose distribution in an exposed population.
$K_n = \sigma_n / D_n$ is the variation coefficient for a normal distribution.
$K_l = \sigma_l / D_l$ is the variation coefficient for a log-normal distribution.

Table S.13.1

$R = R(D_n, D_l)$ for $K_n = 0.1$ and $K_l = 0.1$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	-	-	-	-	-	-	.234E-07	.415E-03	.614E-01	.903E+00	.100E+01	.100E+01
75	-	-	-	-	-	-	-	.226E-07	.294E-04	.612E-01	.675E+00	.986E+00
100		-	-	-	-	-	-	-	.223E-07	.408E-03	.627E-01	.480E+00
125		-	-	-	-	-	-	-	-	.228E-05	.157E-02	.614E-01
150		-	-	-	-	-	-	-	-	.222E-07	.310E-04	.371E-02
175	-	-	-	-	-	-	-	-	-	-	.740E-06	.166E-03
200	-	-	-	-	-	-	-	-	-	-	.248E-07	.753E-05
225	-	-	-	-	-	-	-	-	-	-	.121E-08	.404E-06
250	-	-	-	-	-	-	-	-	-	-	-	.272E-07
300	-	-	-	-	-	-	-	-	-	-	-	-
350	-	-	-	-	-	-	-	-	-	-	-	-
400	-	-	-	-	-	-	-	-	-	-	-	-

Table S.13.2

***R* = *R* (D_n, D_l) for K_n = 0.1 and K_l = 0.2 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	-	-	-	-	-	-	.227E-04	.974E-02	.143E+00	.775E+00	.985E+00	.100E+01
75	-	-	-	-	-	-	.477E-08	.225E-04	.219E-02	.143E+00	.592E+00	.893E+00
100	-	-	-	-	-	-	-	.684E-07	.226E-04	.981E-02	.142E+00	.464E+00
125	-	-	-	-	-	-	-	-	.280E-06	.479E-03	.200E-01	.142E+00
150	-	-	-	-	-	-	-	-	.499E-08	.244E-04	.231E-02	.313E-01
175	-	-	-	-	-	-	-	-	-	.131E-05	.238E-03	.560E-02
200	-	-	-	-	-	-	-	-	-	.783E-07	.244E-04	.919E-03
225	-	-	-	-	-	-	-	-	-	.545E-08	.261E-05	.147E-03
250	-	-	-	-	-	-	-	-	-	.-	.301E-06	.237E-04
300	-	-	-	-	-	-	-	-	-	-	.516E-08	.685E-06
350	-	-	-	-	-	-	-	-	-	-	-	.243E-07
400	-	-	-	-	-	-	-	-	-	-	-	.109E-08

Table S.13.3

$R = R\,(D_n, D_l)$ for $K_n = 0.1$ and $K_l = 0.3$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	-	-	-	-	.152E-08	.818E-07	.113E-02	.390E-01	.200E+00	.680E+00	.921E+00	.984E+00
75	-	-	-	-	-	-	.723E-05	.113E-02	.163E-01	.201E+00	.536E+00	.791E+00
100	-	-	-	-	-	-	.817E-07	.369E-04	.113E-02	.387E-01	.198E+00	.445E+00
125	-	-	-	-	-	-	.152E-08	.153E-05	.845E-04	.664E-02	.595E-01	.199E+00
150	-	-	-	-	-	-	-	.872E-07	.766E-05	.116E-02	.165E-01	.777E-01
175	-	-	-	-	-	-	-	.596E-08	.768E-06	.205E-03	.435E-02	.278E-01
200	-	-	-	-	-	-	-	-	.870E-07	.380E-04	.115E-02	.963E-02
225	-	-	-	-	-	-	-	-	.112E-07	.749E-05	.310E-03	.331E-02
250	-	-	-	-	-	-	-	-	.160E-08	.158E-05	.860E-04	.114E-02
300	-	-	-	-	-	-	-	-	-	.836E-07	.736E-05	.142E-03
350	-	-	-	-	-	-	-	-	-	.556E-08	.727E-06	.192E-04
400	-	-	-	-	-	-	-	-	-	-	.824E-07	.285E-05

Table S.13.4

$R = R(D_n, D_l)$ for $K_n = 0.1$ and $K_l = 0.4$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	-	-	-	.235E-07	.102E-05	.136E-04	.679E-02	.729E-01	.232E+00	.613E+00	.845E+00	.943E+00
75	-	-	-	-	.434E-08	.983E-07	.251E-03	.681E-02	.403E-01	.233E+00	.497E+00	.709E+00
100	-	-	-	-	-	.168E-08	.136E-04	.718E-03	.674E-02	.721E-01	.229E+00	.427E+00
125	-	-	-	-	-	-	.102E-05	.910E-04	.124E-02	.220E-01	.974E-01	.230E+00
150	-	-	-	-	-	-	.104E-06	.141E-04	.257E-03	.688E-02	.404E-01	.117E+00
175	-	-	-	-	-	-	.125E-07	.243E-05	.573E-04	.220E-02	.165E-01	.577E-01
200	-	-	-	-	-	-	.176E-08	.470E-06	.139E-04	.730E-03	.684E-02	.282E-01
225	-	-	-	-	-	-	-	.101E-06	.366E-05	.254E-03	.289E-02	.138E-01
250	-	-	-	-	-	-	-	.240E-07	.103E-05	.921E-04	.125E-02	.682E-02
300	-	-	-	-	-	-	-	.171E-08	.999E-07	.137E-04	.252E-03	.174E-02
350	-	-	-	-	-	-	-	-	.119E-07	.235E-05	.561E-04	.471E-03
400	-	-	-	-	-	-	-	-	.169E-08	.457E-06	.136E-04	.136E-03

Table S.13.5

***R* = *R* (D_n, D_l) for K_n = 0.1 and K_l = 0.5 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	-	-	.281E-07	.214E-05	.311E-04	.196E-03	.172E-01	.101E+00	.248E+00	.563E+00	.775E+00	.889E+00
75	-	-	-	.281E-07	.652E-06	.594E-05	.159E-02	.173E-01	.645E-01	.248E+00	.466E+00	.647E+00
100	-	-	-	-	.281E-07	.332E-06	.195E-03	.335E-02	.171E-01	.997E-01	.245E+00	.409E+00
125	-	-	-	-	.194E-08	.281E-07	.310E-04	.761E-03	.498E-02	.408E-01	.126E+00	.246E+00
150	-	-	-	-	-	.336E-08	.609E-05	.200E-03	.160E-02	.173E-01	.645E-01	.145E+00
175	-	-	-	-	-	-	.135E-05	.571E-04	.545E-03	.754E-02	.331E-01	.844E-01
200	-	-	-	-	-	-	.339E-06	.178E-04	.199E-03	.340E-02	.173E-01	.492E-01
225	-	-	-	-	-	-	.941E-07	.601E-05	.768E-04	.159E-02	.922E-02	.290E-01
250	-	-	-	-	-	-	.285E-07	.217E-05	.313E-04	.768E-03	.502E-02	.173E-01
300	-	-	-	-	-	-	.325E-08	.334E-06	.597E-05	.197E-03	.158E-02	.638E-02
350	-	-	-	-	-	-	-	.619E-07	.132E-05	.562E-04	.539E-03	.249E-02
400	-	-	-	-	-	-	-	.133E-07	.332E-06	.176E-04	.197E-03	.102E-02

Table S.13.6

$R = R(D_n, D_l)$ for $K_n = 0.1$ and $K_l = 0.75$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	-	.188E-06	.248E-04	.272E-03	.121E-02	.344E-02	.467E-01	.141E+00	.257E+00	.480E+00	.646E+00	.760E+00
75	-	.675E-08	.161E-05	.249E-04	.141E-03	.481E-03	.114E-01	.468E-01	.106E+00	.258E+00	.411E+00	.542E+00
100	-	-	.187E-06	.367E-05	.246E-04	.958E-04	.340E-02	.175E-01	.462E-01	.139E+00	.255E+00	.371E+00
125	-	-	.313E-07	.744E-06	.572E-05	.247E-04	.120E-02	.743E-02	.222E-01	.790E-01	.162E+00	.255E+00
150	-	-	.689E-08	.191E-06	.163E-05	.767E-05	.483E-03	.345E-02	.114E-01	.468E-01	.105E+00	.178E+00
175	-	-	.178E-08	.561E-07	.527E-06	.266E-05	.209E-03	.170E-02	.613E-02	.284E-01	.695E-01	.125E+00
200	-	-	-	.186E-07	.190E-06	.102E-05	.972E-04	.883E-03	.345E-02	.177E-01	.467E-01	.889E-01
225	-	-	-	.682E-08	.747E-07	.424E-06	.480E-04	.481E-03	.201E-02	.114E-01	.320E-01	.640E-01
250	-	-	-	.271E-08	.316E-07	.189E-06	.249E-04	.273E-03	.121E-02	.749E-02	.223E-01	.467E-01
300	-	-	-	-	.678E-08	.441E-07	.759E-05	.968E-04	.480E-03	.344E-02	.114E-01	.257E-01
350	-	-	-	-	.174E-08	.122E-07	.263E-05	.383E-04	.208E-03	.169E-02	.611E-02	.148E-01
400	-	-	-	-	-	.385E-08	.101E-05	.164E-04	.967E-04	.879E-03	.344E-02	.882E-02

Table S.13.7

$R = R\ (D_n, D_l)$ for $K_n = 0.1$ and $K_l = 1$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.200E-06	.110E-04	.316E-03	.167E-02	.478E-02	.100E-01	.670E-01	.155E+00	.251E+00	.425E+00	.561E+00	.663E+00
75	.142E-07	.115E-05	.482E-04	.317E-03	.106E-02	.250E-02	.238E-01	.671E-01	.124E+00	.251E+00	.371E+00	.475E+00
100	.187E-08	.199E-06	.109E-04	.841E-04	.313E-03	.804E-03	.993E-02	.324E-01	.663E-01	.154E+00	.249E+00	.340E+00
125	-	.477E-07	.324E-05	.282E-04	.115E-03	.314E-03	.475E-02	.174E-01	.385E-01	.993E-01	.173E+00	.249E+00
150	-	.144E-07	.116E-05	.111E-04	.484E-04	.140E-03	.250E-02	.101E-01	.238E-01	.670E-01	.124E+00	.187E+00
175	-	.493E-08	.460E-06	.482E-05	.223E-04	.676E-04	.139E-02	.607E-02	.152E-01	.463E-01	.902E-01	.142E+00
200	-	.190E-08	.202E-06	.227E-05	.111E-04	.350E-04	.815E-03	.382E-02	.100E-01	.328E-01	.670E-01	.109E+00
225	-	-	.955E-07	.115E-05	.586E-05	.192E-04	.499E-03	.249E-02	.684E-02	.237E-01	.506E-01	.848E-01
250	-	-	.481E-07	.615E-06	.327E-05	.111E-04	.317E-03	.167E-02	.479E-02	.175E-01	.388E-01	.669E-01
300	-	-	.142E-07	.201E-06	.115E-05	.410E-05	.139E-03	.813E-03	.249E-02	.100E-01	.237E-01	.430E-01
350	-	-	.488E-08	.752E-07	.457E-06	.171E-05	.673E-04	.427E-03	.139E-02	.605E-02	.152E-01	.287E-01
400	-	-	.188E-08	.313E-07	.200E-06	.782E-06	.349E-04	.238E-03	.813E-03	.381E-02	.100E-01	.197E-01

Table S.13.8

$R = R\ (D_n, D_l)$ for $K_n = 0.1$ and $K_l = 1.25$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.362E-05	.796E-04	.109E-02	.402E-02	.925E-02	.167E-01	.784E-01	.159E+00	.240E+00	.386E+00	.502E+00	.593E+00
75	.475E-06	.139E-04	.250E-03	.109E-02	.280E-02	.552E-02	.336E-01	.785E-01	.131E+00	.241E+00	.341E+00	.428E+00
100	.100E-06	.358E-05	.788E-04	.385E-03	.107E-02	.225E-02	.166E-01	.432E-01	.778E-01	.158E+00	.239E+00	.315E+00
125	.287E-07	.120E-05	.308E-04	.165E-03	.489E-03	.108E-02	.919E-02	.260E-01	.497E-01	.109E+00	.174E+00	.239E+00
150	.101E-07	.478E-06	.139E-04	.799E-04	.250E-03	.573E-03	.552E-02	.167E-01	.335E-01	.784E-01	.131E+00	.186E+00
175	.399E-08	.211E-06	.685E-05	.419E-04	.137E-03	.325E-03	.347E-02	.112E-01	.233E-01	.578E-01	.100E+00	.147E+00
200	.175E-08	.102E-06	.363E-05	.235E-04	.798E-04	.195E-03	.228E-02	.773E-02	.167E-01	.436E-01	.784E-01	.118E+00
225	-	.528E-07	.205E-05	.139E-04	.488E-04	.122E-03	.155E-02	.551E-02	.123E-01	.335E-01	.622E-01	.954E-01
250	-	.290E-07	.121E-05	.856E-05	.311E-04	.797E-04	.109E-02	.402E-02	.925E-02	.262E-01	.500E-01	.784E-01
300	-	.100E-07	.475E-06	.362E-05	.138E-04	.370E-04	.572E-03	.228E-02	.551E-02	.167E-01	.335E-01	.545E-01
350	-	.396E-08	.210E-06	.170E-05	.681E-05	.189E-04	.324E-03	.137E-02	.346E-02	.112E-01	.233E-01	.391E-01
400	-	.174E-08	.101E-06	.870E-06	.362E-05	.103E-04	.194E-03	.868E-03	.228E-02	.773E-02	.167E-01	.289E-01

Table S.13.9

$R = R(D_n, D_l)$ for $K_n = 0.1$ and $K = 1.5$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.187E-04	.244E-03	.218E-02	.658E-02	.134E-01	.222E-01	.845E-01	.158E+00	.230E+00	.357E+00	.459E+00	.540E+00
75	.350E-05	.571E-04	.635E-03	.218E-02	.484E-02	.860E-02	.403E-01	.846E-01	.133E+00	.230E+00	.317E+00	.393E+00
100	.968E-06	.185E-04	.242E-03	.910E-03	.216E-02	.402E-02	.220E-01	.502E-01	.839E-01	.157E+00	.228E+00	.295E+00
125	.346E-06	.750E-05	.111E-03	.447E-03	.111E-02	.216E-02	.133E-01	.324E-01	.567E-01	.113E+00	.171E+00	.228E+00
150	.146E-06	.351E-05	.572E-04	.245E-03	.635E-03	.127E-02	.859E-02	.222E-01	.403E-01	.845E-01	.133E+00	.182E+00
175	.682E-07	.179E-05	.318E-04	.143E-03	.384E-03	.790E-03	.580E-02	.157E-01	.295E-01	.647E-01	.105E+00	.147E+00
200	.347E-07	.981E-06	.188E-04	.883E-04	.245E-03	.515E-03	.407E-02	.115E-01	.222E-01	.506E-01	.845E-01	.121E+00
225	.189E-07	.571E-06	.117E-04	.571E-04	.162E-03	.349E-03	.294E-02	.859E-02	.170E-01	.403E-01	.690E-01	.100E+00
250	.109E-07	.349E-06	.756E-05	.382E-04	.112E-03	.244E-03	.218E-02	.658E-02	.134E-01	.326E-01	.570E-01	.845E-01
300	.409E-08	.145E-06	.349E-05	.187E-04	.570E-04	.129E-03	.127E-02	.406E-02	.858E-02	.221E-01	.403E-01	.614E-01
350	.175E-08	.679E-07	.178E-05	.101E-04	.317E-04	.737E-04	.789E-03	.265E-02	.579E-02	.157E-01	.295E-01	.461E-01
400	-	.346E-07	.978E-06	.576E-05	.187E-04	.446E-04	.515E-03	.180E-02	.406E-02	.115E-01	.222E-01	.354E-01

Table S.13.10

$R = R(D_n, D_l)$ for $K_n = 0.1$ and $K_l = 1.75$ (doses in rad)

D_n	D_l										
	1	2 4		6	8	10	20	30	40	60	80	100
50	.529E-04	.495E-03	.336E-02	.891E-02	.167E-01	.262E-01	.876E-01	.155E+00	.220E+00	.333E+00	.425E+00	.499E+00
75	.124E-04	.139E-03	.114E-02	.337E-02	.680E-02	.113E-01	.449E-01	.876E-01	.133E+00	.220E+00	.298E+00	.366E+00
100	.406E-05	.524E-04	.490E-03	.156E-02	.333E-02	.577E-02	.260E-01	.546E-01	.869E-01	.154E+00	.219E+00	.278E+00
125	.167E-05	.239E-04	.248E-03	.838E-03	.186E-02	.334E-02	.166E-01	.368E-01	.609E-01	.114E+00	.167E+00	.219E+00
150	.793E-06	.124E-04	.140E-03	.496E-03	.114E-02	.210E-02	.113E-01	.262E-01	.448E-01	.875E-01	.133E+00	.177E+00
175	.411E-06	.690E-05	.836E-04	.310E-03	.734E-03	.138E-02	.798E-02	.193E-01	.339E-01	.687E-01	.107E+00	.146E+00
200	.230E-06	.411E-05	.530E-04	.204E-03	.495E-03	.949E-03	.583E-02	.146E-01	.262E-01	.550E-01	.875E-01	.121E+00
225	.136E-06	.257E-05	.351E-04	.139E-03	.346E-03	.676E-03	.437E-02	.113E-01	.207E-01	.448E-01	.728E-01	.103E+00
250	.845E-07	.168E-05	.241E-04	.983E-04	.250E-03	.495E-03	.336E-02	.891E-02	.167E-01	.371E-01	.613E-01	.875E-01
300	.364E-07	.789E-06	.123E-04	.529E-04	.139E-03	.283E-03	.209E-02	.582E-02	.113E-01	.262E-01	.448E-01	.656E-01
350	.176E-07	.410E-06	.688E-05	.308E-04	.834E-04	.174E-03	.138E-02	.400E-02	.797E-02	.193E-01	.338E-01	.506E-01
400	.921E-08	.229E-06	.410E-05	.190E-04	.529E-04	.113E-03	.948E-03	.285E-02	.582E-02	.146E-01	.262E-01	.399E-01

Table S.13.11

***R* = *R* (D_n, D_l) for K_n = 0.1 and K_l =2 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.107E-03	.797E-03	.450E-02	.109E-01	.193E-01	.292E-01	.889E-01	.152E+00	.211E+00	.314E+00	.398E+00	.467E+00
75	.292E-04	.256E-03	.169E-02	.450E-02	.852E-02	.135E-01	.479E-01	.889E-01	.131E+00	.211E+00	.282E+00	.344E+00
100	.108E-04	.106E-03	.790E-03	.225E-02	.446E-02	.734E-02	.290E-01	.574E-01	.883E-01	.151E+00	.210E+00	.264E+00
125	.487E-05	.526E-04	.428E-03	.128E-02	.264E-02	.447E-02	.192E-01	.399E-01	.635E-01	.114E+00	.163E+00	.210E+00
150	.251E-05	.292E-04	.256E-03	.798E-03	.169E-02	.293E-02	.135E-01	.292E-01	.478E-01	.889E-01	.131E+00	.172E+00
175	.140E-05	.173E-04	.161E-03	.523E-03	.114E-02	.201E-02	.985E-02	.220E-01	.369E-01	.709E-01	.107E+00	.143E+00
200	.834E-06	.109E-04	.107E-03	.359E-03	.798E-03	.143E-02	.741E-02	.171E-01	.292E-01	.578E-01	.889E-01	.121E+00
225	.523E-06	.718E-05	.742E-04	.255E-03	.578E-03	.106E-02	.571E-02	.135E-01	.236E-01	.478E-01	.749E-01	.103E+00
250	.342E-06	.491E-05	.529E-04	.187E-03	.431E-03	.797E-03	.450E-02	.109E-01	.193E-01	.401E-01	.639E-01	.889E-01
300	.162E-06	.250E-05	.291E-04	.107E-03	.255E-03	.483E-03	.293E-02	.740E-02	.135E-01	.292E-01	.478E-01	.680E-01
350	.847E-07	.140E-05	.173E-04	.660E-04	.161E-03	.312E-03	.201E-02	.526E-02	.985E-02	.220E-01	.369E-01	.535E-01
400	.478E-07	.832E-06	.109E-04	.429E-04	.107E-03	.211E-03	.143E-02	.387E-02	.740E-02	.171E-01	.292E-01	.430E-01

Table S.13.12

$R = R(D_n, D_l)$ for $K_n = 0.1$ and $K_l = 2.5$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.260E-03	.145E-02	.643E-02	.139E-01	.229E-01	.330E-01	.890E-01	.145E+00	.196E+00	.285E+00	.358E+00	.418E+00
75	.860E-04	.546E-03	.276E-02	.644E-02	.112E-01	.168E-01	.511E-01	.890E-01	.127E+00	.196E+00	.257E+00	.311E+00
100	.369E-04	.258E-03	.143E-02	.353E-02	.638E-02	.984E-02	.328E-01	.601E-01	.885E-01	.144E+00	.195E+00	.242E+00
125	.189E-04	.142E-03	.848E-03	.217E-02	.405E-02	.639E-02	.228E-01	.434E-01	.657E-01	.111E+00	.154E+00	.195E+00
150	.108E-04	.860E-04	.546E-03	.145E-02	.276E-02	.444E-02	.168E-01	.330E-01	.511E-01	.890E-01	.127E+00	.162E+00
175	.658E-05	.553E-04	.369E-03	.101E-02	.196E-02	.321E-02	.127E-01	.257E-01	.406E-01	.726E-01	.105E+00	.137E+00
200	.425E-05	.373E-04	.260E-03	.730E-03	.145E-02	.240E-02	.992E-02	.206E-01	.330E-01	.604E-01	.890E-01	.117E+00
225	.287E-05	.262E-04	.190E-03	.545E-03	.110E-02	.184E-02	.791E-02	.168E-01	.273E-01	.511E-01	.763E-01	.102E+00
250	.201E-05	.190E-04	.143E-03	.418E-03	.853E-03	.145E-02	.643E-02	.139E-01	.229E-01	.437E-01	.661E-01	.890E-01
300	.107E-05	.108E-04	.859E-04	.260E-03	.545E-03	.941E-03	.444E-02	.991E-02	.168E-01	.330E-01	.511E-01	.699E-01
350	.621E-06	.657E-05	.552E-04	.172E-03	.368E-03	.647E-03	.320E-02	.737E-02	.127E-01	.257E-01	.406E-01	.564E-01
400	.384E-06	.425E-05	.373E-04	.119E-03	.260E-03	.463E-03	.240E-02	.565E-02	.991E-02	.206E-01	.330E-01	.465E-01

Table S.13.13

$R = R\ (D_n, D_l)$ for $K_n = 0.2$ and $K_l = 0.1$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.192E-06	.509E-06	.186E-05	.533E-05	.140E-04	.341E-04	.166E-02	.280E-01	.177E+00	.804E+00	.996E+00	.100E+01
75	.117E-06	.281E-06	.826E-06	.186E-05	.384E-05	.737E-05	.140E-03	.165E-02	.122E-01	.176E+00	.618E+00	.922E+00
100	.839E-07	.192E-06	.510E-06	.103E-05	.188E-05	.320E-05	.344E-04	.271E-03	.165E-02	.279E-01	.178E+00	.494E+00
125	.654E-07	.146E-06	.364E-06	.688E-06	.117E-05	.186E-05	.139E-04	.809E-04	.397E-03	.580E-02	.441E-01	.174E+00
150	.536E-07	.117E-06	.282E-06	.510E-06	.832E-06	.126E-05	.740E-05	.343E-04	.140E-03	.165E-02	.124E-01	.567E-01
175	.453E-07	.980E-07	.229E-06	.403E-06	.637E-06	.937E-06	.463E-05	.181E-04	.636E-04	.606E-03	.417E-02	.197E-01
200	.393E-07	.842E-07	.193E-06	.332E-06	.513E-06	.738E-06	.321E-05	.110E-04	.343E-04	.271E-03	.167E-02	.768E-02
225	.347E-07	.738E-07	.166E-06	.282E-06	.428E-06	.605E-06	.239E-05	.740E-05	.209E-04	.140E-03	.772E-03	.337E-02
250	.310E-07	.656E-07	.146E-06	.245E-06	.367E-06	.510E-06	.187E-05	.534E-05	.139E-04	.808E-04	.401E-03	.164E-02
300	.256E-07	.537E-07	.118E-06	.193E-06	.283E-06	.387E-06	.126E-05	.321E-05	.740E-05	.343E-04	.141E-03	.506E-03
350	.219E-07	.455E-07	.983E-07	.159E-06	.231E-06	.310E-06	.938E-06	.219E-05	.462E-05	.181E-04	.642E-04	.204E-03
400	.190E-07	.394E-07	.844E-07	.135E-06	.194E-06	.259E-06	.738E-06	.162E-05	.321E-05	.110E-04	.346E-04	.990E-04

Table S.13.14

$R = R\ (D_n, D_l)$ for $K_n = 0.2$ and $K_l = 0.2$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.194E-06	.521E-06	.199E-05	.608E-05	.172E-04	.461E-04	.304E-02	.455E-01	.213E+00	.734E+00	.961E+00	.997E+00
75	.118E-06	.285E-06	.856E-06	.199E-05	.426E-05	.862E-05	.218E-03	.303E-02	.215E-01	.214E+00	.582E+00	.847E+00
100	.842E-07	.194E-06	.522E-06	.107E-05	.200E-05	.352E-05	.462E-04	.447E-03	.303E-02	.456E-01	.214E+00	.484E+00
125	.656E-07	.147E-06	.370E-06	.710E-06	.123E-05	.199E-05	.171E-04	.119E-03	.675E-03	.106E-01	.669E-01	.212E+00
150	.537E-07	.118E-06	.286E-06	.523E-06	.861E-06	.133E-05	.864E-05	.461E-04	.217E-03	.304E-02	.215E-01	.842E-01
175	.454E-07	.985E-07	.232E-06	.411E-06	.655E-06	.975E-06	.521E-05	.228E-04	.910E-04	.107E-02	.762E-02	.335E-01
200	.394E-07	.845E-07	.195E-06	.338E-06	.525E-06	.762E-06	.353E-05	.133E-04	.461E-04	.448E-03	.304E-02	.140E-01
225	.347E-07	.740E-07	.168E-06	.286E-06	.436E-06	.621E-06	.258E-05	.863E-05	.267E-04	.218E-03	.136E-02	.629E-02
250	.311E-07	.658E-07	.147E-06	.248E-06	.373E-06	.523E-06	.199E-05	.607E-05	.171E-04	.119E-03	.678E-03	.304E-02
300	.257E-07	.539E-07	.118E-06	.195E-06	.287E-06	.394E-06	.133E-05	.353E-05	.863E-05	.462E-04	.218E-03	.886E-03
350	.219E-07	.456E-07	.987E-07	.160E-06	.233E-06	.315E-06	.976E-06	.235E-05	.521E-05	.229E-04	.914E-04	.331E-03
400	.190E-07	.395E-07	.847E-07	.136E-06	.196E-06	.262E-06	.762E-06	.172E-05	.353E-05	.133E-04	.463E-04	.150E-03

Table S.13.15

***R* = *R* (D_n, D_l) for K_n = 0.2 and K_l = 0.3 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.197E-06	.544E-06	.226E-05	.793E-05	.267E-04	.860E-04	.722E-02	.728E-01	.244E+00	.668E+00	.898E+00	.973E+00
75	.119E-06	.292E-06	.914E-06	.227E-05	.525E-05	.119E-04	.504E-03	.721E-02	.397E-01	.245E+00	.542E+00	.769E+00
100	.848E-07	.197E-06	.545E-06	.116E-05	.227E-05	.426E-05	.858E-04	.109E-02	.722E-02	.730E-01	.243E+00	.466E+00
125	.659E-07	.149E-06	.382E-06	.750E-06	.133E-05	.226E-05	.266E-04	.256E-03	.168E-02	.219E-01	.984E-01	.242E+00
150	.539E-07	.119E-06	.292E-06	.546E-06	.916E-06	.146E-05	.119E-04	.857E-04	.504E-03	.722E-02	.396E-01	.118E+00
175	.456E-07	.993E-07	.236E-06	.426E-06	.687E-06	.105E-05	.664E-05	.374E-04	.190E-03	.266E-02	.165E-01	.571E-01
200	.395E-07	.851E-07	.198E-06	.348E-06	.546E-06	.808E-06	.426E-05	.197E-04	.858E-04	.110E-02	.724E-02	.278E-01
225	.348E-07	.745E-07	.170E-06	.293E-06	.451E-06	.653E-06	.301E-05	.119E-04	.451E-04	.506E-03	.338E-02	.140E-01
250	.311E-07	.662E-07	.149E-06	.253E-06	.383E-06	.545E-06	.226E-05	.791E-05	.266E-04	.258E-03	.169E-02	.725E-02
300	.257E-07	.541E-07	.119E-06	.198E-06	.293E-06	.407E-06	.146E-05	.426E-05	.119E-04	.861E-04	.506E-03	.221E-02
350	.219E-07	.458E-07	.996E-07	.163E-06	.237E-06	.323E-06	.105E-05	.272E-05	.664E-05	.375E-04	.190E-03	.796E-03
400	.191E-07	.396E-07	.854E-07	.138E-06	.199E-06	.267E-06	.808E-06	.192E-05	.427E-05	.198E-04	.861E-04	.334E-03

Table S.13.16

***R* = *R* (D_n, D_l) for K_n = 0.2 and K_l = 0.4 (doses in rad)**

D_n	D_l											
	1	**2 4**		**6**	**8**	**10**	**20**	**30**	**40**	**60**	**80**	**100**
50	.202E-06	.581E-06	.287E-05	.136E-04	.624E-04	.244E-03	.157E-01	.101E+00	.262E+00	.613E+00	.831E+00	.931E+00
75	.121E-06	.303E-06	.102E-05	.287E-05	.804E-05	.228E-04	.150E-02	.157E-01	.624E-01	.263E+00	.507E+00	.702E+00
100	.857E-07	.202E-06	.582E-06	.133E-05	.287E-05	.620E-05	.244E-03	.309E-02	.157E-01	.100E+00	.261E+00	.446E+00
125	.665E-07	.152E-06	.401E-06	.821E-06	.155E-05	.287E-05	.622E-04	.774E-03	.452E-02	.387E-01	.127E+00	.260E+00
150	.543E-07	.121E-06	.303E-06	.583E-06	.102E-05	.172E-05	.227E-04	.244E-03	.150E-02	.157E-01	.621E-01	.147E+00
175	.458E-07	.101E-06	.243E-06	.448E-06	.746E-06	.119E-05	.108E-04	.939E-04	.569E-03	.675E-02	.308E-01	.829E-01
200	.397E-07	.860E-07	.203E-06	.363E-06	.583E-06	.890E-06	.620E-05	.430E-04	.244E-03	.309E-02	.158E-01	.469E-01
225	.350E-07	.751E-07	.174E-06	.304E-06	.476E-06	.706E-06	.403E-05	.228E-04	.117E-03	.151E-02	.831E-02	.269E-01
250	.313E-07	.667E-07	.152E-06	.261E-06	.401E-06	.582E-06	.287E-05	.135E-04	.624E-04	.778E-03	.454E-02	.158E-01
300	.258E-07	.545E-07	.121E-06	.203E-06	.304E-06	.428E-06	.172E-05	.620E-05	.228E-04	.245E-03	.151E-02	.576E-02
350	.220E-07	.460E-07	.101E-06	.166E-06	.244E-06	.336E-06	.119E-05	.357E-05	.108E-04	.942E-04	.570E-03	.230E-02
400	.191E-07	.398E-07	.863E-07	.140E-06	.203E-06	.276E-06	.890E-06	.237E-05	.621E-05	.431E-04	.245E-03	.100E-02

Table S.13.17

***R = R (D_n, D_l)* for K_n=0.2 and K_l = 0.5 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.209E-06	.646E-06	.472E-05	.369E-04	.206E-03	.779E-03	.273E-01	.123E+00	.271E+00	.569E+00	.769E+00	.880E+00
75	.123E-06	.319E-06	.124E-05	.472E-05	.190E-04	.684E-04	.390E-02	.274E-01	.835E-01	.271E+00	.478E+00	.647E+00
100	.869E-07	.209E-06	.648E-06	.171E-05	.472E-05	.135E-04	.779E-03	.716E-02	.273E-01	.123E+00	.270E+00	.427E+00
125	.672E-07	.155E-06	.430E-06	.957E-06	.209E-05	.472E-05	.205E-03	.220E-02	.981E-02	.566E-01	.149E+00	.269E+00
150	.547E-07	.123E-06	.320E-06	.648E-06	.124E-05	.238E-05	.684E-04	.778E-03	.389E-02	.272E-01	.831E-01	.168E+00
175	.462E-07	.102E-06	.254E-06	.485E-06	.857E-06	.149E-05	.279E-04	.312E-03	.168E-02	.137E-01	.472E-01	.105E+00
200	.399E-07	.872E-07	.210E-06	.386E-06	.648E-06	.105E-05	.135E-04	.139E-03	.780E-03	.717E-02	.273E-01	.662E-01
225	.351E-07	.761E-07	.179E-06	.320E-06	.518E-06	.805E-06	.753E-05	.686E-04	.389E-03	.390E-02	.162E-01	.423E-01
250	.314E-07	.674E-07	.156E-06	.273E-06	.430E-06	.647E-06	.472E-05	.369E-04	.206E-03	.221E-02	.987E-02	.274E-01
300	.259E-07	.549E-07	.124E-06	.210E-06	.320E-06	.461E-06	.238E-05	.135E-04	.687E-04	.781E-03	.390E-02	.120E-01
350	.220E-07	.464E-07	.103E-06	.171E-06	.254E-06	.357E-06	.149E-05	.638E-05	.279E-04	.312E-03	.168E-02	.559E-02
400	.192E-07	.401E-07	.875E-07	.144E-06	.210E-06	.290E-06	.105E-05	.364E-05	.135E-04	.139E-03	.780E-03	.276E-02

Table S.13.18

***R* = *R* (D_n, D_l) for K_n = 0.2 and K_l = 0.75 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.252E-06	.198E-05	.709E-04	.550E-03	.205E-02	.522E-02	.559E-01	.155E+00	.272E+00	.488E+00	.649E+00	.759E+00
75	.134E-06	.473E-06	.817E-05	.709E-04	.310E-03	.905E-03	.154E-01	.560E-01	.119E+00	.272E+00	.422E+00	.548E+00
100	.919E-07	.253E-06	.198E-05	.153E-04	.709E-04	.224E-03	.521E-02	.230E-01	.557E-01	.154E+00	.271E+00	.385E+00
125	.700E-07	.175E-06	.819E-06	.474E-05	.215E-04	.707E-04	.205E-02	.105E-01	.283E-01	.908E-01	.176E+00	.270E+00
150	.565E-07	.134E-06	.474E-06	.198E-05	.816E-05	.268E-04	.902E-03	.521E-02	.154E-01	.557E-01	.118E+00	.192E+00
175	.474E-07	.109E-06	.330E-06	.105E-05	.372E-05	.118E-04	.435E-03	.276E-02	.877E-02	.353E-01	.804E-01	.139E+00
200	.408E-07	.922E-07	.254E-06	.664E-06	.198E-05	.585E-05	.225E-03	.155E-02	.522E-02	.230E-01	.559E-01	.101E+00
225	.359E-07	.798E-07	.207E-06	.474E-06	.121E-05	.325E-05	.123E-03	.906E-03	.323E-02	.154E-01	.395E-01	.747E-01
250	.320E-07	.703E-07	.175E-06	.367E-06	.821E-06	.199E-05	.711E-04	.551E-03	.206E-02	.105E-01	.284E-01	.559E-01
300	.263E-07	.568E-07	.135E-06	.254E-06	.474E-06	.948E-06	.269E-04	.225E-03	.905E-03	.522E-02	.154E-01	.324E-01
350	.223E-07	.476E-07	.110E-06	.195E-06	.330E-06	.573E-06	.118E-04	.102E-03	.435E-03	.277E-02	.877E-02	.195E-01
400	.194E-07	.410E-07	.925E-07	.159E-06	.254E-06	.403E-06	.585E-05	.504E-04	.225E-03	.155E-02	.522E-02	.122E-01

Table S.13.19

$R = R\ (D_n, D_l)$ for $K_n = 0.2$ and $K_l = 1$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.901E-06	.236E-04	.497E-03	.233E-02	.621E-02	.124E-01	.746E-01	.165E+00	.262E+00	.434E+00	.567E+00	.666E+00
75	.212E-06	.338E-05	.885E-04	.498E-03	.152E-02	.338E-02	.280E-01	.746E-01	.134E+00	.262E+00	.381E+00	.482E+00
100	.111E-06	.902E-06	.236E-04	.149E-03	.496E-03	.119E-02	.124E-01	.378E-01	.743E-01	.165E+00	.261E+00	.351E+00
125	.776E-07	.374E-06	.810E-05	.547E-04	.196E-03	.495E-03	.618E-02	.209E-01	.442E-01	.109E+00	.184E+00	.260E+00
150	.605E-07	.212E-06	.338E-05	.235E-04	.882E-04	.233E-03	.336E-02	.124E-01	.279E-01	.743E-01	.133E+00	.197E+00
175	.499E-07	.146E-06	.164E-05	.113E-04	.439E-04	.120E-03	.195E-02	.774E-02	.183E-01	.524E-01	.987E-01	.151E+00
200	.425E-07	.112E-06	.903E-06	.596E-05	.236E-04	.662E-04	.119E-02	.503E-02	.124E-01	.379E-01	.745E-01	.118E+00
225	.371E-07	.914E-07	.556E-06	.339E-05	.135E-04	.386E-04	.757E-03	.338E-02	.869E-02	.280E-01	.571E-01	.933E-01
250	.329E-07	.779E-07	.375E-06	.206E-05	.814E-05	.236E-04	.498E-03	.233E-02	.621E-02	.210E-01	.445E-01	.745E-01
300	.269E-07	.608E-07	.213E-06	.904E-06	.339E-05	.990E-05	.234E-03	.119E-02	.337E-02	.124E-01	.280E-01	.491E-01
350	.227E-07	.501E-07	.146E-06	.483E-06	.164E-05	.471E-05	.120E-03	.655E-03	.195E-02	.775E-02	.183E-01	.335E-01
400	.197E-07	.427E-07	.112E-06	.302E-06	.903E-06	.249E-05	.662E-04	.382E-03	.119E-02	.503E-02	.124E-01	.235E-01

Table S.13.20

$R = R(D_n, D_l)$ for $K_n = 0.2$ and $K_l = 1.25$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.689E-05	.121E-03	.143E-02	.495E-02	.110E-01	.193E-01	.848E-01	.167E+00	.249E+00	.394E+00	.508E+00	.597E+00
75	.116E-05	.236E-04	.355E-03	.143E-02	.351E-02	.669E-02	.375E-01	.849E-01	.139E+00	.249E+00	.349E+00	.435E+00
100	.350E-06	.689E-05	.121E-03	.537E-03	.142E-02	.287E-02	.192E-01	.481E-01	.845E-01	.166E+00	.249E+00	.325E+00
125	.157E-06	.258E-05	.497E-04	.240E-03	.671E-03	.142E-02	.109E-01	.295E-01	.548E-01	.116E+00	.183E+00	.248E+00
150	.928E-07	.116E-05	.235E-04	.120E-03	.353E-03	.773E-03	.666E-02	.192E-01	.374E-01	.846E-01	.139E+00	.194E+00
175	.651E-07	.601E-06	.123E-04	.659E-04	.201E-03	.453E-03	.429E-02	.131E-01	.265E-01	.631E-01	.107E+00	.155E+00
200	.506E-07	.350E-06	.690E-05	.384E-04	.121E-03	.280E-03	.288E-02	.923E-02	.193E-01	.482E-01	.847E-01	.125E+00
225	.419E-07	.226E-06	.412E-05	.236E-04	.762E-04	.181E-03	.200E-02	.668E-02	.144E-01	.375E-01	.678E-01	.102E+00
250	.359E-07	.158E-06	.259E-05	.151E-04	.500E-04	.121E-03	.143E-02	.495E-02	.110E-01	.296E-01	.551E-01	.847E-01
300	.284E-07	.931E-07	.116E-05	.690E-05	.236E-04	.589E-04	.776E-03	.288E-02	.668E-02	.193E-01	.375E-01	.598E-01
350	.236E-07	.654E-07	.602E-06	.351E-05	.123E-04	.314E-04	.453E-03	.178E-02	.429E-02	.131E-01	.265E-01	.435E-01
400	.202E-07	.508E-07	.351E-06	.195E-05	.689E-05	.180E-04	.280E-03	.115E-02	.288E-02	.923E-02	.193E-01	.325E-01

Table S.13.21

$R = R(D_n, D_l)$ for $K_n = 0.2$ and $K_l = 1.5$ (doses in rad)

D_n	D_l											
	1	**2 4**		**6**	**8**	**10**	**20**	**30**	**40**	**60**	**80**	**100**
50	.281E-04	.324E-03	.264E-02	.766E-02	.152E-01	.247E-01	.900E-01	.165E+00	.237E+00	.364E+00	.465E+00	.545E+00
75	.580E-05	.809E-04	.809E-03	.265E-02	.570E-02	.991E-02	.440E-01	.901E-01	.140E+00	.237E+00	.325E+00	.400E+00
100	.180E-05	.281E-04	.324E-03	.115E-02	.263E-02	.480E-02	.246E-01	.546E-01	.898E-01	.164E+00	.237E+00	.303E+00
125	.717E-06	.119E-04	.152E-03	.579E-03	.139E-02	.263E-02	.151E-01	.357E-01	.612E-01	.119E+00	.179E+00	.236E+00
150	.345E-06	.578E-05	.806E-04	.323E-03	.806E-03	.157E-02	.987E-02	.246E-01	.439E-01	.898E-01	.140E+00	.189E+00
175	.192E-06	.311E-05	.462E-04	.194E-03	.499E-03	.996E-03	.677E-02	.177E-01	.325E-01	.694E-01	.111E+00	.154E+00
200	.119E-06	.180E-05	.281E-04	.123E-03	.324E-03	.662E-03	.481E-02	.131E-01	.247E-01	.548E-01	.900E-01	.127E+00
225	.817E-07	.111E-05	.180E-04	.809E-04	.219E-03	.456E-03	.352E-02	.989E-02	.192E-01	.440E-01	.739E-01	.106E+00
250	.603E-07	.721E-06	.119E-04	.553E-04	.153E-03	.324E-03	.264E-02	.765E-02	.151E-01	.358E-01	.615E-01	.900E-01
300	.387E-07	.346E-06	.580E-05	.281E-04	.809E-04	.176E-03	.157E-02	.481E-02	.989E-02	.247E-01	.440E-01	.661E-01
350	.286E-07	.192E-06	.311E-05	.156E-04	.462E-04	.103E-03	.997E-03	.319E-02	.678E-02	.177E-01	.325E-01	.501E-01
400	.230E-07	.120E-06	.180E-05	.926E-05	.281E-04	.641E-04	.662E-03	.221E-02	.481E-02	.131E-01	.247E-01	.388E-01

Table S.13.22

$R = R(D_n, D_l)$ for $K_n = 0.2$ and $K_l = 1.75$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.712E-04	.614E-03	.391E-02	.101E-01	.185E-01	.287E-01	.925E-01	.161E+00	.227E+00	.340E+00	.431E+00	.505E+00
75	.177E-04	.181E-03	.137E-02	.392E-02	.774E-02	.127E-01	.483E-01	.925E-01	.139E+00	.227E+00	.305E+00	.372E+00
100	.618E-05	.711E-04	.612E-03	.188E-02	.390E-02	.664E-02	.286E-01	.587E-01	.922E-01	.161E+00	.226E+00	.286E+00
125	.266E-05	.333E-04	.315E-03	.102E-02	.221E-02	.389E-02	.184E-01	.399E-01	.651E-01	.120E+00	.174E+00	.226E+00
150	.132E-05	.176E-04	.180E-03	.612E-03	.137E-02	.247E-02	.126E-01	.286E-01	.481E-01	.922E-01	.138E+00	.183E+00
175	.726E-06	.101E-04	.110E-03	.390E-03	.896E-03	.165E-02	.902E-02	.212E-01	.367E-01	.729E-01	.112E+00	.151E+00
200	.433E-06	.619E-05	.713E-04	.260E-03	.613E-03	.115E-02	.666E-02	.162E-01	.287E-01	.588E-01	.924E-01	.127E+00
225	.276E-06	.398E-05	.480E-04	.181E-03	.435E-03	.829E-03	.505E-02	.127E-01	.228E-01	.482E-01	.773E-01	.108E+00
250	.186E-06	.267E-05	.335E-04	.129E-03	.317E-03	.614E-03	.391E-02	.101E-01	.185E-01	.401E-01	.654E-01	.924E-01
300	.966E-07	.132E-05	.177E-04	.713E-04	.181E-03	.359E-03	.247E-02	.666E-02	.127E-01	.287E-01	.482E-01	.698E-01
350	.583E-07	.727E-06	.101E-04	.424E-04	.110E-03	.224E-03	.165E-02	.463E-02	.903E-02	.213E-01	.367E-01	.543E-01
400	.395E-07	.433E-06	.619E-05	.267E-04	.712E-04	.147E-03	.115E-02	.333E-02	.666E-02	.162E-01	.287E-01	.431E-01

Table S.13.23

***R* = *R* (D_n, D_l) for K_n = 0.2 and K_l = 2 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.136E-03	.950E-03	.510E-02	.121E-01	.211E-01	.316E-01	.934E-01	.157E+00	.217E+00	.320E+00	.404E+00	.472E+00
75	.386E-04	.315E-03	.197E-02	.511E-02	.950E-02	.149E-01	.510E-01	.934E-01	.136E+00	.217E+00	.288E+00	.350E+00
100	.149E-04	.136E-03	.948E-03	.262E-02	.509E-02	.827E-02	.315E-01	.611E-01	.931E-01	.157E+00	.217E+00	.271E+00
125	.691E-05	.683E-04	.520E-03	.151E-02	.304E-02	.508E-02	.210E-01	.428E-01	.673E-01	.119E+00	.169E+00	.216E+00
150	.364E-05	.384E-04	.314E-03	.948E-03	.197E-02	.336E-02	.149E-01	.315E-01	.509E-01	.931E-01	.136E+00	.177E+00
175	.210E-05	.233E-04	.202E-03	.630E-03	.134E-02	.233E-02	.109E-01	.239E-01	.396E-01	.748E-01	.112E+00	.148E+00
200	.129E-05	.149E-04	.136E-03	.438E-03	.950E-03	.168E-02	.829E-02	.187E-01	.315E-01	.613E-01	.933E-01	.126E+00
225	.835E-06	.100E-04	.951E-04	.315E-03	.696E-03	.125E-02	.644E-02	.149E-01	.256E-01	.510E-01	.790E-01	.108E+00
250	.565E-06	.695E-05	.687E-04	.233E-03	.523E-03	.950E-03	.510E-02	.121E-01	.211E-01	.430E-01	.676E-01	.933E-01
300	.287E-06	.366E-05	.385E-04	.136E-03	.315E-03	.585E-03	.336E-02	.829E-02	.149E-01	.316E-01	.510E-01	.719E-01
350	.163E-06	.210E-05	.233E-04	.850E-04	.202E-03	.382E-03	.233E-02	.595E-02	.109E-01	.240E-01	.396E-01	.569E-01
400	.101E-06	.129E-05	.149E-04	.561E-04	.136E-03	.262E-03	.168E-02	.441E-02	.829E-02	.187E-01	.316E-01	.460E-01

Table S.13.24

***R* = *R* (D_n, D_l) for K_n = 0.2 and K_l = 2.5 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.309E-03	.165E-02	.709E-02	.151E-01	.246E-01	.351E-01	.928E-01	.149E+00	.201E+00	.290E+00	.363E+00	.423E+00
75	.105E-03	.637E-03	.311E-02	.710E-02	.122E-01	.181E-01	.539E-01	.928E-01	.131E+00	.201E+00	.263E+00	.316E+00
100	.465E-04	.308E-03	.165E-02	.396E-02	.707E-02	.108E-01	.350E-01	.634E-01	.925E-01	.149E+00	.201E+00	.248E+00
125	.241E-04	.171E-03	.981E-03	.246E-02	.452E-02	.705E-02	.245E-01	.460E-01	.691E-01	.115E+00	.160E+00	.200E+00
150	.139E-04	.105E-03	.634E-03	.165E-02	.309E-02	.492E-02	.181E-01	.351E-01	.538E-01	.926E-01	.131E+00	.167E+00
175	.862E-05	.682E-04	.434E-03	.116E-02	.222E-02	.359E-02	.138E-01	.275E-01	.430E-01	.760E-01	.109E+00	.141E+00
200	.565E-05	.466E-04	.309E-03	.845E-03	.165E-02	.270E-02	.108E-01	.221E-01	.351E-01	.635E-01	.927E-01	.122E+00
225	.387E-05	.330E-04	.228E-03	.636E-03	.126E-02	.209E-02	.868E-02	.181E-01	.292E-01	.539E-01	.798E-01	.106E+00
250	.274E-05	.242E-04	.172E-03	.491E-03	.986E-03	.165E-02	.709E-02	.151E-01	.246E-01	.462E-01	.694E-01	.928E-01
300	.150E-05	.139E-04	.105E-03	.309E-03	.636E-03	.109E-02	.493E-02	.108E-01	.181E-01	.351E-01	.539E-01	.733E-01
350	.890E-06	.862E-05	.682E-04	.207E-03	.434E-03	.752E-03	.359E-02	.810E-02	.138E-01	.275E-01	.430E-01	.594E-01
400	.564E-06	.565E-05	.466E-04	.145E-03	.309E-03	.543E-03	.270E-02	.625E-02	.108E-01	.221E-01	.351E-01	.491E-01

Table S.13.25

$R = R(D_n, D_l)$ for $K_n = 0.3$ and $K_l = 0.1$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.114E-03	.258E-03	.656E-03	.126E-02	.217E-02	.346E-02	.233E-01	.952E-01	.259E+00	.731E+00	.966E+00	.100E+01
75	.733E-04	.159E-03	.373E-03	.657E-03	.104E-02	.152E-02	.703E-02	.233E-01	.625E-01	.259E+00	.586E+00	.846E+00
100	.540E-04	.115E-03	.258E-03	.437E-03	.661E-03	.928E-03	.347E-02	.971E-02	.233E-01	.952E-01	.261E+00	.497E+00
125	.427E-04	.897E-04	.197E-03	.325E-03	.480E-03	.657E-03	.216E-02	.536E-02	.117E-01	.431E-01	.121E+00	.258E+00
150	.353E-04	.736E-04	.159E-03	.259E-03	.375E-03	.505E-03	.152E-02	.347E-02	.703E-02	.233E-01	.630E-01	.138E+00
175	.301E-04	.624E-04	.134E-03	.214E-03	.307E-03	.409E-03	.116E-02	.249E-02	.475E-02	.144E-01	.367E-01	.795E-01
200	.262E-04	.542E-04	.115E-03	.183E-03	.260E-03	.343E-03	.928E-03	.190E-02	.347E-02	.970E-02	.235E-01	.495E-01
225	.232E-04	.478E-04	.101E-03	.159E-03	.225E-03	.295E-03	.771E-03	.152E-02	.268E-02	.703E-02	.162E-01	.330E-01
250	.209E-04	.428E-04	.899E-04	.141E-03	.199E-03	.259E-03	.657E-03	.126E-02	.216E-02	.536E-02	.118E-01	.232E-01
300	.173E-04	.354E-04	.738E-04	.115E-03	.160E-03	.208E-03	.505E-03	.928E-03	.152E-02	.347E-02	.708E-02	.131E-01
350	.148E-04	.302E-04	.625E-04	.970E-04	.135E-03	.173E-03	.409E-03	.729E-03	.116E-02	.249E-02	.478E-02	.844E-02
400	.129E-04	.263E-04	.543E-04	.838E-04	.116E-03	.148E-03	.343E-03	.598E-03	.928E-03	.190E-02	.350E-02	.592E-02

Table S.13.26

$R = R(D_n, D_l)$ for $K_n = 0.3$ and $K_l = 0.2$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.115E-03	.260E-03	.669E-03	.130E-02	.227E-02	.369E-02	.266E-01	.108E+00	.275E+00	.694E+00	.925E+00	.987E+00
75	.735E-04	.160E-03	.377E-03	.670E-03	.107E-02	.158E-02	.769E-02	.265E-01	.715E-01	.276E+00	.568E+00	.797E+00
100	.540E-04	.115E-03	.260E-03	.443E-03	.673E-03	.951E-03	.370E-02	.108E-01	.265E-01	.108E+00	.276E+00	.492E+00
125	.427E-04	.899E-04	.198E-03	.329E-03	.486E-03	.669E-03	.226E-02	.580E-02	.130E-01	.496E-01	.135E+00	.274E+00
150	.353E-04	.738E-04	.160E-03	.261E-03	.379E-03	.513E-03	.158E-02	.370E-02	.768E-02	.266E-01	.718E-01	.154E+00
175	.301E-04	.625E-04	.134E-03	.216E-03	.310E-03	.414E-03	.119E-02	.262E-02	.511E-02	.161E-01	.419E-01	.908E-01
200	.262E-04	.543E-04	.115E-03	.184E-03	.262E-03	.347E-03	.952E-03	.198E-02	.370E-02	.108E-01	.267E-01	.569E-01
225	.232E-04	.479E-04	.101E-03	.160E-03	.227E-03	.298E-03	.788E-03	.158E-02	.283E-02	.770E-02	.182E-01	.378E-01
250	.209E-04	.429E-04	.901E-04	.142E-03	.200E-03	.261E-03	.670E-03	.130E-02	.226E-02	.580E-02	.131E-01	.265E-01
300	.173E-04	.355E-04	.739E-04	.116E-03	.161E-03	.209E-03	.513E-03	.952E-03	.158E-02	.370E-02	.772E-02	.148E-01
350	.148E-04	.302E-04	.627E-04	.974E-04	.135E-03	.174E-03	.414E-03	.744E-03	.119E-02	.262E-02	.514E-02	.932E-02
400	.129E-04	.263E-04	.544E-04	.841E-04	.116E-03	.149E-03	.347E-03	.608E-03	.952E-03	.199E-02	.371E-02	.645E-02

Table S.13.27

$R = R(D_n, D_l)$ for $K_n = 0.3$ and $K_l = 0.3$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.115E-03	.263E-03	.691E-03	.138E-02	.246E-02	.414E-02	.326E-01	.126E+00	.290E+00	.651E+00	.869E+00	.956E+00
75	.738E-04	.161E-03	.384E-03	.693E-03	.111E-02	.168E-02	.900E-02	.326E-01	.858E-01	.290E+00	.542E+00	.742E+00
100	.542E-04	.116E-03	.264E-03	.453E-03	.693E-03	.994E-03	.414E-02	.128E-01	.326E-01	.126E+00	.290E+00	.479E+00
125	.428E-04	.903E-04	.201E-03	.335E-03	.497E-03	.692E-03	.246E-02	.667E-02	.157E-01	.604E-01	.154E+00	.289E+00
150	.354E-04	.740E-04	.161E-03	.265E-03	.386E-03	.526E-03	.169E-02	.414E-02	.900E-02	.326E-01	.858E-01	.174E+00
175	.301E-04	.627E-04	.135E-03	.219E-03	.314E-03	.423E-03	.126E-02	.287E-02	.585E-02	.196E-01	.511E-01	.107E+00
200	.263E-04	.544E-04	.116E-03	.186E-03	.265E-03	.353E-03	.994E-03	.214E-02	.414E-02	.128E-01	.326E-01	.691E-01
225	.233E-04	.480E-04	.102E-03	.162E-03	.229E-03	.302E-03	.818E-03	.169E-02	.312E-02	.902E-02	.220E-01	.464E-01
250	.209E-04	.430E-04	.906E-04	.143E-03	.201E-03	.264E-03	.692E-03	.138E-02	.246E-02	.669E-02	.157E-01	.326E-01
300	.173E-04	.355E-04	.742E-04	.116E-03	.162E-03	.211E-03	.526E-03	.995E-03	.169E-02	.415E-02	.901E-02	.179E-01
350	.148E-04	.303E-04	.629E-04	.980E-04	.136E-03	.175E-03	.423E-03	.771E-03	.126E-02	.287E-02	.585E-02	.110E-01
400	.129E-04	.264E-04	.545E-04	.846E-04	.117E-03	.150E-03	.353E-03	.627E-03	.995E-03	.215E-02	.414E-02	.748E-02

Table S.13.28

R = R (D_n, D_l) for K_n = 0.3 and K_l = 0.4 (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.116E-03	.269E-03	.727E-03	.151E-02	.281E-02	.492E-02	.414E-01	.144E+00	.298E+00	.610E+00	.812E+00	.914E+00
75	.742E-04	.163E-03	.396E-03	.727E-03	.120E-02	.187E-02	.113E-01	.414E-01	.102E+00	.299E+00	.516E+00	.690E+00
100	.544E-04	.117E-03	.269E-03	.468E-03	.727E-03	.106E-02	.492E-02	.163E-01	.414E-01	.144E+00	.298E+00	.462E+00
125	.429E-04	.910E-04	.204E-03	.343E-03	.515E-03	.727E-03	.281E-02	.823E-02	.201E-01	.740E-01	.171E+00	.297E+00
150	.355E-04	.745E-04	.164E-03	.270E-03	.396E-03	.547E-03	.187E-02	.493E-02	.113E-01	.414E-01	.102E+00	.191E+00
175	.302E-04	.630E-04	.137E-03	.222E-03	.321E-03	.436E-03	.137E-02	.331E-02	.715E-02	.251E-01	.635E-01	.125E+00
200	.263E-04	.546E-04	.117E-03	.189E-03	.270E-03	.362E-03	.106E-02	.242E-02	.493E-02	.163E-01	.414E-01	.839E-01
225	.233E-04	.482E-04	.103E-03	.164E-03	.232E-03	.309E-03	.866E-03	.187E-02	.363E-02	.113E-01	.282E-01	.580E-01
250	.209E-04	.431E-04	.913E-04	.145E-03	.204E-03	.270E-03	.727E-03	.150E-02	.281E-02	.824E-02	.201E-01	.414E-01
300	.173E-04	.356E-04	.747E-04	.117E-03	.164E-03	.214E-03	.547E-03	.106E-02	.187E-02	.493E-02	.113E-01	.229E-01
350	.148E-04	.303E-04	.632E-04	.987E-04	.137E-03	.178E-03	.436E-03	.814E-03	.137E-02	.332E-02	.715E-02	.140E-01
400	.129E-04	.264E-04	.548E-04	.851E-04	.117E-03	.152E-03	.362E-03	.656E-03	.107E-02	.242E-02	.493E-02	.929E-02

Table S.13.29

***R* = *R* (D_n, D_l) for K_n = 0.3 and K_l = 0.5 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.118E-03	.276E-03	.781E-03	.171E-02	.339E-02	.624E-02	.518E-01	.159E+00	.301E+00	.573E+00	.759E+00	.867E+00
75	.747E-04	.166E-03	.412E-03	.781E-03	.134E-02	.217E-02	.148E-01	.518E-01	.117E+00	.301E+00	.491E+00	.645E+00
100	.547E-04	.118E-03	.277E-03	.491E-03	.781E-03	.118E-02	.624E-02	.214E-01	.518E-01	.159E+00	.300E+00	.444E+00
125	.431E-04	.918E-04	.208E-03	.355E-03	.542E-03	.781E-03	.339E-02	.107E-01	.261E-01	.878E-01	.185E+00	.300E+00
150	.356E-04	.750E-04	.166E-03	.277E-03	.412E-03	.578E-03	.217E-02	.624E-02	.148E-01	.517E-01	.117E+00	.204E+00
175	.303E-04	.634E-04	.139E-03	.227E-03	.332E-03	.456E-03	.154E-02	.407E-02	.924E-02	.324E-01	.765E-01	.140E+00
200	.264E-04	.549E-04	.119E-03	.192E-03	.277E-03	.376E-03	.118E-02	.288E-02	.624E-02	.214E-01	.518E-01	.984E-01
225	.234E-04	.484E-04	.104E-03	.167E-03	.238E-03	.319E-03	.941E-03	.217E-02	.449E-02	.148E-01	.362E-01	.706E-01
250	.210E-04	.433E-04	.921E-04	.147E-03	.208E-03	.277E-03	.781E-03	.171E-02	.339E-02	.107E-01	.261E-01	.518E-01
300	.174E-04	.357E-04	.753E-04	.119E-03	.167E-03	.219E-03	.578E-03	.118E-02	.217E-02	.624E-02	.148E-01	.297E-01
350	.148E-04	.304E-04	.636E-04	.996E-04	.139E-03	.181E-03	.456E-03	.882E-03	.154E-02	.407E-02	.924E-02	.183E-01
400	.130E-04	.265E-04	.551E-04	.858E-04	.119E-03	.154E-03	.376E-03	.700E-03	.118E-02	.288E-02	.624E-02	.121E-01

Table S.13.30

$R = R\ (D_n, D_l)$ for $K_n = 0.3$ and $K_l = 0.75$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.123E-03	.311E-03	.109E-02	.292E-02	.645E-02	.121E-01	.755E-01	.179E+00	.294E+00	.500E+00	.651E+00	.756E+00
75	.768E-04	.177E-03	.494E-03	.109E-02	.215E-02	.388E-02	.270E-01	.756E-01	.142E+00	.294E+00	.437E+00	.556E+00
100	.558E-04	.124E-03	.311E-03	.610E-03	.109E-02	.183E-02	.121E-01	.369E-01	.755E-01	.179E+00	.293E+00	.402E+00
125	.438E-04	.950E-04	.226E-03	.414E-03	.689E-03	.109E-02	.645E-02	.202E-01	.435E-01	.114E+00	.201E+00	.293E+00
150	.360E-04	.771E-04	.178E-03	.312E-03	.495E-03	.746E-03	.388E-02	.121E-01	.269E-01	.754E-01	.142E+00	.217E+00
175	.306E-04	.649E-04	.146E-03	.249E-03	.383E-03	.559E-03	.257E-02	.783E-02	.176E-01	.519E-01	.102E+00	.163E+00
200	.266E-04	.560E-04	.124E-03	.208E-03	.312E-03	.443E-03	.183E-02	.538E-02	.121E-01	.369E-01	.755E-01	.124E+00
225	.236E-04	.493E-04	.108E-03	.178E-03	.262E-03	.366E-03	.138E-02	.388E-02	.868E-02	.269E-01	.568E-01	.961E-01
250	.211E-04	.440E-04	.953E-04	.155E-03	.227E-03	.312E-03	.109E-02	.293E-02	.645E-02	.202E-01	.436E-01	.755E-01
300	.175E-04	.362E-04	.774E-04	.124E-03	.178E-03	.240E-03	.747E-03	.183E-02	.388E-02	.121E-01	.270E-01	.484E-01
350	.149E-04	.308E-04	.651E-04	.103E-03	.146E-03	.195E-03	.559E-03	.127E-02	.257E-02	.784E-02	.176E-01	.324E-01
400	.130E-04	.268E-04	.562E-04	.885E-04	.124E-03	.164E-03	.443E-03	.950E-03	.183E-02	.538E-02	.121E-01	.226E-01

Table S.13.31

$R = R\ (D_n, D_l)$ for $K_n = 0.3$ and $K_l = 1$ (doses in rad)

D_n	D_l										
	1	2 4		6	8	10	20	30	40	60	80	100
50	.134E-03	.399E-03	.186E-02	.531E-02	.112E-01	.196E-01	.904E-01	.184E+00	.280E+00	.447E+00	.574E+00	.669E+00
75	.805E-04	.202E-03	.713E-03	.186E-02	.390E-02	.700E-02	.386E-01	.904E-01	.152E+00	.280E+00	.395E+00	.493E+00
100	.576E-04	.135E-03	.399E-03	.927E-03	.186E-02	.329E-02	.196E-01	.501E-01	.903E-01	.184E+00	.279E+00	.367E+00
125	.449E-04	.101E-03	.270E-03	.571E-03	.108E-02	.186E-02	.112E-01	.303E-01	.574E-01	.126E+00	.203E+00	.279E+00
150	.368E-04	.808E-04	.203E-03	.399E-03	.713E-03	.119E-02	.699E-02	.196E-01	.385E-01	.902E-01	.152E+00	.216E+00
175	.311E-04	.674E-04	.162E-03	.303E-03	.517E-03	.830E-03	.467E-02	.133E-01	.270E-01	.663E-01	.116E+00	.170E+00
200	.270E-04	.578E-04	.135E-03	.243E-03	.399E-03	.621E-03	.329E-02	.949E-02	.196E-01	.501E-01	.903E-01	.136E+00
225	.238E-04	.507E-04	.116E-03	.203E-03	.323E-03	.489E-03	.243E-02	.699E-02	.146E-01	.386E-01	.715E-01	.110E+00
250	.213E-04	.451E-04	.101E-03	.174E-03	.270E-03	.399E-03	.186E-02	.531E-02	.112E-01	.303E-01	.575E-01	.903E-01
300	.176E-04	.369E-04	.810E-04	.135E-03	.203E-03	.289E-03	.119E-02	.329E-02	.699E-02	.196E-01	.386E-01	.626E-01
350	.150E-04	.313E-04	.676E-04	.110E-03	.162E-03	.225E-03	.831E-03	.221E-02	.467E-02	.134E-01	.270E-01	.450E-01
400	.131E-04	.271E-04	.580E-04	.934E-04	.135E-03	.184E-03	.622E-03	.158E-02	.329E-02	.950E-02	.196E-01	.333E-01

Table S.13.32

$R = R(D_n, D_l)$ for $K_n = 0.3$ and $Kl = 1.25$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.158E-03	.587E-03	.306E-02	.823E-02	.160E-01	.262E-01	.981E-01	.183E+00	.265E+00	.407E+00	.518E+00	.603E+00
75	.875E-04	.258E-03	.114E-02	.307E-02	.620E-02	.106E-01	.471E-01	.981E-01	.154E+00	.265E+00	.363E+00	.447E+00
100	.607E-04	.158E-03	.587E-03	.151E-02	.306E-02	.530E-02	.261E-01	.588E-01	.979E-01	.182E+00	.264E+00	.339E+00
125	.466E-04	.113E-03	.367E-03	.888E-03	.177E-02	.306E-02	.160E-01	.381E-01	.662E-01	.131E+00	.199E+00	.264E+00
150	.379E-04	.879E-04	.259E-03	.587E-03	.114E-02	.195E-02	.105E-01	.261E-01	.470E-01	.979E-01	.154E+00	.210E+00
175	.319E-04	.720E-04	.197E-03	.423E-03	.793E-03	.134E-02	.732E-02	.187E-01	.345E-01	.750E-01	.122E+00	.170E+00
200	.275E-04	.610E-04	.158E-03	.323E-03	.588E-03	.977E-03	.530E-02	.139E-01	.261E-01	.588E-01	.979E-01	.140E+00
225	.243E-04	.530E-04	.132E-03	.259E-03	.456E-03	.744E-03	.397E-02	.106E-01	.203E-01	.470E-01	.801E-01	.116E+00
250	.217E-04	.468E-04	.113E-03	.214E-03	.367E-03	.588E-03	.306E-02	.823E-02	.160E-01	.382E-01	.663E-01	.980E-01
300	.179E-04	.380E-04	.880E-04	.158E-03	.259E-03	.399E-03	.196E-02	.530E-02	.106E-01	.262E-01	.470E-01	.714E-01
350	.152E-04	.320E-04	.721E-04	.125E-03	.197E-03	.295E-03	.134E-02	.363E-02	.732E-02	.187E-01	.346E-01	.537E-01
400	.132E-04	.277E-04	.611E-04	.103E-03	.158E-03	.230E-03	.977E-03	.261E-02	.530E-02	.139E-01	.262E-01	.414E-01

Table S.13.33

***R* = *R* (D_n, D_l) for K_n = 0.3 and K_l = 1.5 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.203E-03	.882E-03	.446E-02	.110E-01	.201E-01	.311E-01	.102E+00	.178E+00	.251E+00	.376E+00	.475E+00	.553E+00
75	.101E-03	.360E-03	.173E-02	.446E-02	.853E-02	.138E-01	.526E-01	.102E+00	.153E+00	.251E+00	.337E+00	.411E+00
100	.667E-04	.203E-03	.882E-03	.228E-02	.445E-02	.738E-02	.311E-01	.642E-01	.101E+00	.178E+00	.251E+00	.317E+00
125	.498E-04	.137E-03	.533E-03	.135E-02	.265E-02	.445E-02	.201E-01	.435E-01	.714E-01	.132E+00	.193E+00	.251E+00
150	.397E-04	.102E-03	.360E-03	.882E-03	.173E-02	.291E-02	.138E-01	.311E-01	.525E-01	.101E+00	.153E+00	.203E+00
175	.331E-04	.808E-04	.263E-03	.621E-03	.120E-02	.203E-02	.990E-02	.230E-01	.399E-01	.798E-01	.123E+00	.167E+00
200	.284E-04	.670E-04	.203E-03	.463E-03	.882E-03	.148E-02	.738E-02	.176E-01	.311E-01	.642E-01	.102E+00	.140E+00
225	.249E-04	.572E-04	.164E-03	.360E-03	.674E-03	.113E-02	.567E-02	.138E-01	.248E-01	.525E-01	.846E-01	.119E+00
250	.222E-04	.500E-04	.137E-03	.290E-03	.533E-03	.882E-03	.445E-02	.110E-01	.201E-01	.436E-01	.715E-01	.102E+00
300	.182E-04	.399E-04	.102E-03	.203E-03	.360E-03	.584E-03	.292E-02	.739E-02	.138E-01	.311E-01	.526E-01	.764E-01
350	.154E-04	.333E-04	.809E-04	.154E-03	.263E-03	.417E-03	.203E-02	.522E-02	.991E-02	.231E-01	.399E-01	.592E-01
400	.134E-04	.285E-04	.671E-04	.123E-03	.204E-03	.315E-03	.148E-02	.384E-02	.739E-02	.176E-01	.311E-01	.469E-01

Table S.13.34

$R = R\ (D_n, D_l)$ for $K_n = 0.3$ and $K_l = 1.75$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.272E-03	.125E-02	.582E-02	.134E-01	.233E-01	.347E-01	.103E+00	.173E+00	.239E+00	.351E+00	.441E+00	.513E+00
75	.125E-03	.503E-03	.239E-02	.582E-02	.106E-01	.165E-01	.561E-01	.103E+00	.150E+00	.239E+00	.317E+00	.383E+00
100	.772E-04	.273E-03	.125E-02	.311E-02	.581E-02	.928E-02	.346E-01	.673E-01	.103E+00	.173E+00	.239E+00	.298E+00
125	.553E-04	.175E-03	.754E-03	.188E-02	.358E-02	.581E-02	.232E-01	.471E-01	.742E-01	.131E+00	.187E+00	.239E+00
150	.430E-04	.125E-03	.503E-03	.125E-02	.239E-02	.391E-02	.165E-01	.346E-01	.560E-01	.103E+00	.150E+00	.196E+00
175	.353E-04	.960E-04	.361E-03	.881E-03	.169E-02	.279E-02	.122E-01	.263E-01	.435E-01	.823E-01	.123E+00	.163E+00
200	.299E-04	.775E-04	.273E-03	.653E-03	.125E-02	.207E-02	.928E-02	.206E-01	.347E-01	.674E-01	.103E+00	.138E+00
225	.260E-04	.647E-04	.215E-03	.503E-03	.956E-03	.158E-02	.727E-02	.165E-01	.281E-01	.560E-01	.868E-01	.119E+00
250	.230E-04	.555E-04	.175E-03	.401E-03	.755E-03	.125E-02	.582E-02	.134E-01	.232E-01	.472E-01	.743E-01	.103E+00
300	.187E-04	.432E-04	.125E-03	.273E-03	.504E-03	.827E-03	.392E-02	.928E-02	.165E-01	.347E-01	.560E-01	.790E-01
350	.157E-04	.354E-04	.962E-04	.200E-03	.361E-03	.586E-03	.279E-02	.674E-02	.122E-01	.264E-01	.436E-01	.625E-01
400	.136E-04	.300E-04	.776E-04	.155E-03	.273E-03	.438E-03	.207E-02	.507E-02	.929E-02	.206E-01	.347E-01	.505E-01

Table S.13.35

R = *R* (D_n, D_l) for K_n = 0.3 and K_l = 2 (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.363E-03	.164E-02	.705E-02	.154E-01	.256E-01	.372E-01	.103E+00	.168E+00	.229E+00	.331E+00	.414E+00	.481E+00
75	.158E-03	.677E-03	.306E-02	.705E-02	.123E-01	.186E-01	.582E-01	.103E+00	.147E+00	.229E+00	.300E+00	.361E+00
100	.931E-04	.363E-03	.164E-02	.391E-02	.704E-02	.109E-01	.372E-01	.691E-01	.103E+00	.168E+00	.228E+00	.282E+00
125	.640E-04	.228E-03	.101E-02	.244E-02	.447E-02	.704E-02	.256E-01	.495E-01	.757E-01	.129E+00	.180E+00	.228E+00
150	.483E-04	.159E-03	.676E-03	.164E-02	.305E-02	.486E-02	.186E-01	.371E-01	.581E-01	.103E+00	.147E+00	.189E+00
175	.387E-04	.119E-03	.483E-03	.117E-02	.219E-02	.353E-02	.140E-01	.288E-01	.459E-01	.834E-01	.122E+00	.159E+00
200	.323E-04	.933E-04	.363E-03	.875E-03	.164E-02	.266E-02	.109E-01	.229E-01	.372E-01	.691E-01	.103E+00	.136E+00
225	.277E-04	.763E-04	.284E-03	.676E-03	.127E-02	.207E-02	.868E-02	.186E-01	.306E-01	.582E-01	.877E-01	.118E+00
250	.242E-04	.642E-04	.228E-03	.538E-03	.101E-02	.164E-02	.705E-02	.154E-01	.256E-01	.496E-01	.758E-01	.103E+00
300	.194E-04	.485E-04	.159E-03	.363E-03	.677E-03	.110E-02	.487E-02	.109E-01	.186E-01	.372E-01	.582E-01	.803E-01
350	.162E-04	.389E-04	.119E-03	.263E-03	.484E-03	.787E-03	.353E-02	.808E-02	.140E-01	.288E-01	.460E-01	.644E-01
400	.140E-04	.324E-04	.935E-04	.200E-03	.363E-03	.588E-03	.266E-02	.619E-02	.109E-01	.229E-01	.372E-01	.528E-01

Table S.13.36

$R = R (D_n, D_l)$ for $K_n = 0.3$ and $K_l = 2.5$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.579E-03	.242E-02	.904E-02	.182E-01	.288E-01	.402E-01	.101E+00	.159E+00	.211E+00	.300E+00	.373E+00	.432E+00
75	.249E-03	.106E-02	.426E-02	.904E-02	.149E-01	.216E-01	.602E-01	.101E+00	.140E+00	.211E+00	.273E+00	.326E+00
100	.140E-03	.580E-03	.242E-02	.532E-02	.903E-02	.134E-01	.401E-01	.703E-01	.101E+00	.159E+00	.211E+00	.258E+00
125	.912E-04	.363E-03	.154E-02	.346E-02	.600E-02	.902E-02	.287E-01	.520E-01	.763E-01	.124E+00	.169E+00	.211E+00
150	.656E-04	.249E-03	.106E-02	.242E-02	.425E-02	.647E-02	.215E-01	.401E-01	.601E-01	.101E+00	.140E+00	.177E+00
175	.504E-04	.183E-03	.766E-03	.177E-02	.315E-02	.485E-02	.167E-01	.319E-01	.486E-01	.834E-01	.118E+00	.151E+00
200	.405E-04	.140E-03	.580E-03	.135E-02	.242E-02	.375E-02	.134E-01	.260E-01	.401E-01	.703E-01	.101E+00	.130E+00
225	.337E-04	.112E-03	.453E-03	.106E-02	.191E-02	.298E-02	.109E-01	.215E-01	.337E-01	.601E-01	.873E-01	.114E+00
250	.288E-04	.915E-04	.364E-03	.849E-03	.154E-02	.242E-02	.903E-02	.182E-01	.287E-01	.521E-01	.764E-01	.101E+00
300	.222E-04	.658E-04	.250E-03	.580E-03	.106E-02	.167E-02	.648E-02	.134E-01	.216E-01	.402E-01	.602E-01	.805E-01
350	.181E-04	.505E-04	.183E-03	.420E-03	.767E-03	.122E-02	.485E-02	.102E-01	.167E-01	.319E-01	.486E-01	.660E-01
400	.153E-04	.406E-04	.140E-03	.318E-03	.580E-03	.925E-03	.375E-02	.804E-02	.134E-01	.260E-01	.402E-01	.551E-01

Table S.13.37

$R = R\ (D_n, D_l)$ for $K_n = 0.4$ and $K_l = 0.1$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.926E-03	.198E-02	.452E-02	.772E-02	.118E-01	.167E-01	.616E-01	.155E+00	.306E+00	.678E+00	.917E+00	.986E+00
75	.605E-03	.127E-02	.277E-02	.452E-02	.661E-02	.897E-02	.275E-01	.616E-01	.118E+00	.306E+00	.561E+00	.780E+00
100	.449E-03	.930E-03	.199E-02	.318E-02	.455E-02	.604E-02	.167E-01	.343E-01	.616E-01	.155E+00	.308E+00	.493E+00
125	.357E-03	.734E-03	.155E-02	.245E-02	.346E-02	.453E-02	.117E-01	.227E-01	.389E-01	.922E-01	.182E+00	.305E+00
150	.296E-03	.607E-03	.127E-02	.199E-02	.278E-02	.362E-02	.897E-02	.167E-01	.275E-01	.616E-01	.118E+00	.199E+00
175	.253E-03	.517E-03	.108E-02	.167E-02	.233E-02	.301E-02	.723E-02	.130E-01	.209E-01	.446E-01	.832E-01	.138E+00
200	.221E-03	.450E-03	.932E-03	.144E-02	.200E-02	.257E-02	.604E-02	.107E-01	.167E-01	.343E-01	.620E-01	.101E+00
225	.196E-03	.399E-03	.822E-03	.127E-02	.175E-02	.225E-02	.518E-02	.897E-02	.138E-01	.275E-01	.484E-01	.774E-01
250	.176E-03	.358E-03	.736E-03	.113E-02	.156E-02	.199E-02	.453E-02	.773E-02	.117E-01	.227E-01	.391E-01	.615E-01
300	.146E-03	.297E-03	.608E-03	.933E-03	.128E-02	.163E-02	.361E-02	.604E-02	.897E-02	.167E-01	.277E-01	.421E-01
350	.125E-03	.254E-03	.518E-03	.792E-03	.108E-02	.137E-02	.300E-02	.494E-02	.723E-02	.130E-01	.210E-01	.312E-01
400	.110E-03	.222E-03	.451E-03	.688E-03	.938E-03	.119E-02	.257E-02	.418E-02	.604E-02	.107E-01	.168E-01	.244E-01

Table S.13.38

***R* = *R* (D_n, D_l) for K_n = 0.4 and K_l = 0.2 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.928E-03	.199E-02	.456E-02	.784E-02	.120E-01	.171E-01	.646E-01	.163E+00	.313E+00	.657E+00	.881E+00	.964E+00
75	.605E-03	.127E-02	.278E-02	.457E-02	.669E-02	.911E-02	.284E-01	.646E-01	.124E+00	.314E+00	.552E+00	.749E+00
100	.449E-03	.931E-03	.200E-02	.320E-02	.459E-02	.611E-02	.171E-01	.356E-01	.646E-01	.163E+00	.315E+00	.490E+00
125	.357E-03	.735E-03	.155E-02	.246E-02	.348E-02	.457E-02	.120E-01	.234E-01	.405E-01	.972E-01	.190E+00	.313E+00
150	.296E-03	.608E-03	.127E-02	.200E-02	.280E-02	.364E-02	.911E-02	.171E-01	.284E-01	.647E-01	.124E+00	.208E+00
175	.253E-03	.517E-03	.108E-02	.168E-02	.234E-02	.302E-02	.732E-02	.133E-01	.215E-01	.466E-01	.873E-01	.145E+00
200	.221E-03	.451E-03	.934E-03	.145E-02	.201E-02	.258E-02	.611E-02	.108E-01	.171E-01	.357E-01	.649E-01	.106E+00
225	.196E-03	.399E-03	.824E-03	.128E-02	.176E-02	.225E-02	.523E-02	.911E-02	.141E-01	.285E-01	.505E-01	.815E-01
250	.176E-03	.358E-03	.737E-03	.114E-02	.156E-02	.200E-02	.457E-02	.784E-02	.120E-01	.235E-01	.407E-01	.645E-01
300	.146E-03	.297E-03	.609E-03	.935E-03	.128E-02	.163E-02	.364E-02	.611E-02	.911E-02	.171E-01	.286E-01	.440E-01
350	.125E-03	.254E-03	.519E-03	.794E-03	.108E-02	.138E-02	.302E-02	.499E-02	.732E-02	.133E-01	.216E-01	.324E-01
400	.110E-03	.222E-03	.452E-03	.690E-03	.939E-03	.119E-02	.258E-02	.421E-02	.611E-02	.109E-01	.172E-01	.252E-01

Table S.13.39

R = R (D_n, D_l) for K_n = 0.4 and K_l = 0.3 (doses in rad)

D_n	D_l										
	1	2 4		6	8	10	20	30	40	60	80	100
50	.931E-03	.200E-02	.463E-02	.804E-02	.124E-01	.178E-01	.696E-01	.174E+00	.321E+00	.629E+00	.833E+00	.930E+00
75	.606E-03	.128E-02	.281E-02	.464E-02	.681E-02	.936E-02	.301E-01	.696E-01	.133E+00	.322E+00	.535E+00	.710E+00
100	.449E-03	.934E-03	.201E-02	.324E-02	.464E-02	.622E-02	.179E-01	.380E-01	.697E-01	.174E+00	.321E+00	.481E+00
125	.357E-03	.737E-03	.156E-02	.249E-02	.351E-02	.464E-02	.124E-01	.247E-01	.433E-01	.105E+00	.201E+00	.320E+00
150	.296E-03	.609E-03	.128E-02	.201E-02	.282E-02	.368E-02	.936E-02	.179E-01	.301E-01	.698E-01	.133E+00	.219E+00
175	.253E-03	.518E-03	.108E-02	.169E-02	.235E-02	.305E-02	.749E-02	.138E-01	.226E-01	.501E-01	.939E-01	.155E+00
200	.221E-03	.451E-03	.937E-03	.146E-02	.202E-02	.261E-02	.622E-02	.112E-01	.179E-01	.380E-01	.697E-01	.115E+00
225	.196E-03	.400E-03	.826E-03	.128E-02	.176E-02	.227E-02	.532E-02	.936E-02	.147E-01	.302E-01	.541E-01	.880E-01
250	.176E-03	.359E-03	.739E-03	.114E-02	.157E-02	.201E-02	.463E-02	.803E-02	.124E-01	.247E-01	.434E-01	.696E-01
300	.146E-03	.297E-03	.610E-03	.939E-03	.128E-02	.164E-02	.368E-02	.623E-02	.936E-02	.179E-01	.302E-01	.471E-01
350	.125E-03	.254E-03	.520E-03	.797E-03	.109E-02	.138E-02	.305E-02	.507E-02	.749E-02	.138E-01	.226E-01	.344E-01
400	.110E-03	.222E-03	.453E-03	.692E-03	.940E-03	.119E-02	.260E-02	.427E-02	.623E-02	.112E-01	.179E-01	.266E-01

Table S.13.40

***R* = *R* (D_n, D_l) for K_n = 0.4 and K_l = 0.4 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.935E-03	.202E-02	.473E-02	.832E-02	.130E-01	.190E-01	.764E-01	.184E+00	.325E+00	.599E+00	.785E+00	.889E+00
75	.608E-03	.128E-02	.285E-02	.474E-02	.701E-02	.973E-02	.326E-01	.765E-01	.144E+00	.325E+00	.515E+00	.671E+00
100	.450E-03	.939E-03	.203E-02	.329E-02	.474E-02	.640E-02	.190E-01	.414E-01	.765E-01	.185E+00	.325E+00	.469E+00
125	.358E-03	.740E-03	.158E-02	.252E-02	.356E-02	.474E-02	.130E-01	.266E-01	.474E-01	.114E+00	.211E+00	.324E+00
150	.297E-03	.610E-03	.129E-02	.203E-02	.285E-02	.375E-02	.973E-02	.190E-01	.327E-01	.765E-01	.144E+00	.229E+00
175	.253E-03	.520E-03	.109E-02	.171E-02	.237E-02	.310E-02	.774E-02	.146E-01	.243E-01	.549E-01	.103E+00	.166E+00
200	.221E-03	.452E-03	.942E-03	.147E-02	.203E-02	.264E-02	.640E-02	.117E-01	.190E-01	.415E-01	.765E-01	.125E+00
225	.196E-03	.400E-03	.830E-03	.129E-02	.178E-02	.230E-02	.545E-02	.974E-02	.155E-01	.327E-01	.592E-01	.963E-01
250	.176E-03	.359E-03	.742E-03	.115E-02	.158E-02	.203E-02	.474E-02	.831E-02	.130E-01	.266E-01	.474E-01	.764E-01
300	.147E-03	.298E-03	.612E-03	.943E-03	.129E-02	.165E-02	.375E-02	.640E-02	.974E-02	.190E-01	.327E-01	.516E-01
350	.125E-03	.254E-03	.521E-03	.800E-03	.109E-02	.139E-02	.310E-02	.519E-02	.775E-02	.146E-01	.243E-01	.375E-01
400	.110E-03	.222E-03	.454E-03	.694E-03	.943E-03	.120E-02	.264E-02	.436E-02	.641E-02	.117E-01	.190E-01	.288E-01

Table S.13.41

$R = R(D_n, D_l)$ for $K_n = 0.4$ and $K_l = 0.5$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.941E-03	.205E-02	.487E-02	.872E-02	.139E-01	.206E-01	.841E-01	.194E+00	.325E+00	.569E+00	.741E+00	.846E+00
75	.610E-03	.129E-02	.290E-02	.488E-02	.731E-02	.103E-01	.360E-01	.841E-01	.153E+00	.325E+00	.495E+00	.634E+00
100	.452E-03	.944E-03	.206E-02	.336E-02	.488E-02	.665E-02	.206E-01	.459E-01	.842E-01	.194E+00	.325E+00	.454E+00
125	.358E-03	.743E-03	.159E-02	.255E-02	.364E-02	.488E-02	.139E-01	.292E-01	.525E-01	.124E+00	.219E+00	.324E+00
150	.297E-03	.613E-03	.130E-02	.206E-02	.290E-02	.384E-02	.103E-01	.206E-01	.360E-01	.841E-01	.153E+00	.236E+00
175	.254E-03	.521E-03	.110E-02	.172E-02	.241E-02	.316E-02	.809E-02	.156E-01	.265E-01	.607E-01	.112E+00	.176E+00
200	.221E-03	.454E-03	.947E-03	.148E-02	.206E-02	.268E-02	.665E-02	.124E-01	.206E-01	.459E-01	.841E-01	.134E+00
225	.196E-03	.401E-03	.835E-03	.130E-02	.180E-02	.233E-02	.563E-02	.103E-01	.167E-01	.360E-01	.655E-01	.105E+00
250	.176E-03	.360E-03	.746E-03	.116E-02	.159E-02	.206E-02	.488E-02	.872E-02	.139E-01	.292E-01	.524E-01	.841E-01
300	.147E-03	.298E-03	.615E-03	.949E-03	.130E-02	.167E-02	.384E-02	.665E-02	.103E-01	.206E-01	.360E-01	.571E-01
350	.125E-03	.255E-03	.523E-03	.804E-03	.110E-02	.140E-02	.316E-02	.536E-02	.810E-02	.156E-01	.265E-01	.414E-01
400	.110E-03	.222E-03	.455E-03	.697E-03	.949E-03	.121E-02	.268E-02	.448E-02	.666E-02	.125E-01	.206E-01	.316E-01

Table S.13.42

$R = R(D_n, D_l)$ for $K_n = 0.4$ and $K_l = 0.75$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.962E-03	.215E-02	.546E-02	.104E-01	.173E-01	.264E-01	.101E+00	.205E+00	.314E+00	.505E+00	.647E+00	.746E+00
75	.619E-03	.133E-02	.311E-02	.546E-02	.853E-02	.125E-01	.463E-01	.101E+00	.169E+00	.314E+00	.447E+00	.558E+00
100	.456E-03	.966E-03	.216E-02	.364E-02	.546E-02	.769E-02	.264E-01	.583E-01	.101E+00	.205E+00	.313E+00	.415E+00
125	.361E-03	.757E-03	.165E-02	.271E-02	.397E-02	.546E-02	.173E-01	.376E-01	.661E-01	.141E+00	.227E+00	.313E+00
150	.299E-03	.622E-03	.134E-02	.216E-02	.311E-02	.420E-02	.125E-01	.264E-01	.463E-01	.101E+00	.169E+00	.241E+00
175	.255E-03	.528E-03	.112E-02	.179E-02	.255E-02	.341E-02	.957E-02	.197E-01	.342E-01	.755E-01	.129E+00	.189E+00
200	.223E-03	.459E-03	.968E-03	.153E-02	.216E-02	.286E-02	.769E-02	.154E-01	.264E-01	.583E-01	.101E+00	.151E+00
225	.197E-03	.405E-03	.851E-03	.134E-02	.187E-02	.246E-02	.640E-02	.125E-01	.211E-01	.463E-01	.810E-01	.123E+00
250	.177E-03	.363E-03	.759E-03	.119E-02	.165E-02	.216E-02	.546E-02	.104E-01	.173E-01	.376E-01	.661E-01	.101E+00
300	.147E-03	.301E-03	.624E-03	.969E-03	.134E-02	.174E-02	.420E-02	.770E-02	.125E-01	.264E-01	.463E-01	.715E-01
350	.126E-03	.256E-03	.529E-03	.818E-03	.113E-02	.145E-02	.341E-02	.606E-02	.957E-02	.197E-01	.342E-01	.530E-01
400	.110E-03	.224E-03	.460E-03	.708E-03	.969E-03	.124E-02	.286E-02	.497E-02	.770E-02	.154E-01	.264E-01	.408E-01

Table S.13.43

***R* = *R* (D_n, D_l) for K_n = 0.4 and K_l = 1 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.995E-03	.233E-02	.645E-02	.129E-01	.218E-01	.328E-01	.111E+00	.205E+00	.297E+00	.456E+00	.576E+00	.666E+00
75	.632E-03	.140E-02	.347E-02	.645E-02	.105E-01	.156E-01	.555E-01	.111E+00	.174E+00	.297E+00	.407E+00	.500E+00
100	.464E-03	.100E-02	.234E-02	.413E-02	.646E-02	.937E-02	.329E-01	.684E-01	.111E+00	.205E+00	.297E+00	.381E+00
125	.366E-03	.777E-03	.176E-02	.300E-02	.455E-02	.646E-02	.218E-01	.459E-01	.765E-01	.148E+00	.224E+00	.297E+00
150	.302E-03	.635E-03	.140E-02	.234E-02	.348E-02	.484E-02	.156E-01	.328E-01	.555E-01	.111E+00	.173E+00	.236E+00
175	.257E-03	.537E-03	.117E-02	.192E-02	.280E-02	.384E-02	.118E-01	.247E-01	.420E-01	.860E-01	.137E+00	.191E+00
200	.224E-03	.466E-03	.100E-02	.162E-02	.234E-02	.317E-02	.937E-02	.193E-01	.328E-01	.683E-01	.111E+00	.158E+00
225	.199E-03	.411E-03	.876E-03	.141E-02	.201E-02	.270E-02	.768E-02	.156E-01	.264E-01	.555E-01	.915E-01	.132E+00
250	.178E-03	.368E-03	.779E-03	.124E-02	.176E-02	.234E-02	.646E-02	.129E-01	.218E-01	.459E-01	.765E-01	.111E+00
300	.148E-03	.304E-03	.637E-03	.100E-02	.141E-02	.185E-02	.484E-02	.938E-02	.156E-01	.328E-01	.555E-01	.820E-01
350	.126E-03	.259E-03	.539E-03	.842E-03	.117E-02	.153E-02	.384E-02	.723E-02	.118E-01	.247E-01	.420E-01	.627E-01
400	.110E-03	.225E-03	.467E-03	.726E-03	.100E-02	.130E-02	.317E-02	.582E-02	.938E-02	.193E-01	.328E-01	.494E-01

Table S.13.44

***R* = *R* (D_n, D_l) for K_n = 0.4 and K_l = 1.25 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.105E-02	.261E-02	.775E-02	.156E-01	.260E-01	.382E-01	.116E+00	.201E+00	.281E+00	.417E+00	.523E+00	.605E+00
75	.652E-03	.151E-02	.401E-02	.775E-02	.127E-01	.188E-01	.619E-01	.116E+00	.173E+00	.281E+00	.375E+00	.455E+00
100	.474E-03	.105E-02	.262E-02	.483E-02	.775E-02	.114E-01	.382E-01	.747E-01	.116E+00	.200E+00	.280E+00	.353E+00
125	.372E-03	.808E-03	.192E-02	.342E-02	.536E-02	.775E-02	.259E-01	.520E-01	.826E-01	.150E+00	.217E+00	.280E+00
150	.306E-03	.655E-03	.151E-02	.262E-02	.402E-02	.573E-02	.188E-01	.382E-01	.618E-01	.116E+00	.172E+00	.228E+00
175	.260E-03	.551E-03	.124E-02	.211E-02	.318E-02	.447E-02	.144E-01	.293E-01	.479E-01	.919E-01	.140E+00	.188E+00
200	.226E-03	.476E-03	.105E-02	.176E-02	.262E-02	.364E-02	.114E-01	.232E-01	.382E-01	.747E-01	.116E+00	.158E+00
225	.200E-03	.419E-03	.916E-03	.151E-02	.222E-02	.305E-02	.927E-02	.188E-01	.312E-01	.618E-01	.972E-01	.135E+00
250	.180E-03	.374E-03	.809E-03	.132E-02	.192E-02	.262E-02	.775E-02	.156E-01	.259E-01	.520E-01	.827E-01	.116E+00
300	.149E-03	.308E-03	.657E-03	.106E-02	.151E-02	.203E-02	.573E-02	.114E-01	.188E-01	.382E-01	.618E-01	.881E-01
350	.127E-03	.262E-03	.553E-03	.878E-03	.124E-02	.165E-02	.447E-02	.872E-02	.144E-01	.293E-01	.479E-01	.691E-01
400	.111E-03	.227E-03	.477E-03	.752E-03	.106E-02	.139E-02	.364E-02	.696E-02	.114E-01	.232E-01	.382E-01	.557E-01

Table S.13.45

***R* = *R* (D_n, D_l) for K_n = 0.4 and K_l = 1.5 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.112E-02	.297E-02	.911E-02	.181E-01	.293E-01	.421E-01	.117E+00	.194E+00	.266E+00	.387E+00	.482E+00	.557E+00
75	.681E-03	.165E-02	.466E-02	.911E-02	.148E-01	.217E-01	.658E-01	.117E+00	.169E+00	.266E+00	.350E+00	.421E+00
100	.488E-03	.113E-02	.297E-02	.564E-02	.911E-02	.133E-01	.421E-01	.783E-01	.117E+00	.194E+00	.266E+00	.330E+00
125	.381E-03	.851E-03	.214E-02	.394E-02	.628E-02	.911E-02	.293E-01	.560E-01	.859E-01	.148E+00	.209E+00	.266E+00
150	.312E-03	.684E-03	.165E-02	.297E-02	.466E-02	.671E-02	.216E-01	.421E-01	.657E-01	.117E+00	.169E+00	.219E+00
175	.264E-03	.571E-03	.134E-02	.236E-02	.365E-02	.521E-02	.167E-01	.328E-01	.519E-01	.947E-01	.139E+00	.183E+00
200	.229E-03	.491E-03	.113E-02	.195E-02	.297E-02	.421E-02	.133E-01	.263E-01	.421E-01	.783E-01	.117E+00	.156E+00
225	.203E-03	.430E-03	.972E-03	.165E-02	.249E-02	.350E-02	.109E-01	.216E-01	.348E-01	.658E-01	.997E-01	.135E+00
250	.181E-03	.382E-03	.853E-03	.143E-02	.214E-02	.297E-02	.911E-02	.181E-01	.293E-01	.560E-01	.859E-01	.117E+00
300	.150E-03	.313E-03	.685E-03	.113E-02	.166E-02	.227E-02	.672E-02	.133E-01	.216E-01	.421E-01	.658E-01	.911E-01
350	.128E-03	.266E-03	.573E-03	.930E-03	.134E-02	.182E-02	.521E-02	.102E-01	.167E-01	.328E-01	.520E-01	.729E-01
400	.111E-03	.230E-03	.492E-03	.789E-03	.113E-02	.152E-02	.421E-02	.818E-02	.133E-01	.264E-01	.421E-01	.597E-01

Table S.13.46

$R = R(D_n, D_l)$ for $K_n = 0.4$ and $K_l = 1.75$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.122E-02	.337E-02	.104E-01	.202E-01	.319E-01	.448E-01	.117E+00	.188E+00	.253E+00	.362E+00	.449E+00	.518E+00
75	.719E-03	.183E-02	.533E-02	.104E-01	.167E-01	.239E-01	.681E-01	.117E+00	.165E+00	.253E+00	.329E+00	.393E+00
100	.508E-03	.122E-02	.337E-02	.646E-02	.104E-01	.150E-01	.448E-01	.801E-01	.117E+00	.188E+00	.253E+00	.310E+00
125	.392E-03	.909E-03	.240E-02	.450E-02	.718E-02	.104E-01	.318E-01	.585E-01	.873E-01	.146E+00	.201E+00	.253E+00
150	.320E-03	.722E-03	.183E-02	.337E-02	.533E-02	.768E-02	.239E-01	.448E-01	.680E-01	.117E+00	.165E+00	.210E+00
175	.270E-03	.598E-03	.147E-02	.266E-02	.416E-02	.597E-02	.186E-01	.354E-01	.545E-01	.957E-01	.138E+00	.178E+00
200	.233E-03	.510E-03	.122E-02	.218E-02	.337E-02	.481E-02	.150E-01	.288E-01	.448E-01	.801E-01	.117E+00	.153E+00
225	.205E-03	.445E-03	.105E-02	.183E-02	.281E-02	.398E-02	.123E-01	.239E-01	.375E-01	.680E-01	.100E+00	.133E+00
250	.184E-03	.394E-03	.911E-03	.158E-02	.240E-02	.337E-02	.104E-01	.202E-01	.318E-01	.586E-01	.874E-01	.117E+00
300	.152E-03	.321E-03	.724E-03	.122E-02	.183E-02	.255E-02	.768E-02	.150E-01	.239E-01	.448E-01	.680E-01	.923E-01
350	.129E-03	.271E-03	.599E-03	.997E-03	.147E-02	.203E-02	.597E-02	.116E-01	.186E-01	.354E-01	.546E-01	.749E-01
400	.112E-03	.234E-03	.511E-03	.839E-03	.123E-02	.167E-02	.481E-02	.933E-02	.150E-01	.288E-01	.448E-01	.621E-01

Table S.13.47

***R* = *R* (*Dn*, *Dl*) for *Kn* = 0.4 and *Kl* = 2 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.133E-02	.378E-02	.115E-01	.218E-01	.337E-01	.466E-01	.116E+00	.182E+00	.242E+00	.342E+00	.422E+00	.487E+00
75	.766E-03	.202E-02	.598E-02	.115E-01	.181E-01	.256E-01	.693E-01	.116E+00	.160E+00	.242E+00	.311E+00	.371E+00
100	.533E-03	.133E-02	.378E-02	.723E-02	.115E-01	.164E-01	.466E-01	.808E-01	.115E+00	.182E+00	.241E+00	.294E+00
125	.407E-03	.979E-03	.267E-02	.505E-02	.802E-02	.115E-01	.337E-01	.600E-01	.877E-01	.143E+00	.194E+00	.241E+00
150	.330E-03	.769E-03	.203E-02	.378E-02	.598E-02	.856E-02	.256E-01	.465E-01	.692E-01	.115E+00	.160E+00	.202E+00
175	.277E-03	.631E-03	.162E-02	.297E-02	.467E-02	.668E-02	.202E-01	.373E-01	.561E-01	.957E-01	.135E+00	.173E+00
200	.238E-03	.535E-03	.133E-02	.242E-02	.378E-02	.539E-02	.164E-01	.306E-01	.466E-01	.808E-01	.115E+00	.149E+00
225	.209E-03	.464E-03	.113E-02	.203E-02	.314E-02	.447E-02	.136E-01	.256E-01	.393E-01	.692E-01	.100E+00	.131E+00
250	.187E-03	.409E-03	.981E-03	.174E-02	.267E-02	.378E-02	.115E-01	.218E-01	.337E-01	.600E-01	.877E-01	.116E+00
300	.154E-03	.331E-03	.770E-03	.134E-02	.203E-02	.285E-02	.857E-02	.164E-01	.256E-01	.466E-01	.692E-01	.924E-01
350	.130E-03	.278E-03	.633E-03	.108E-02	.162E-02	.225E-02	.668E-02	.128E-01	.202E-01	.373E-01	.562E-01	.758E-01
400	.113E-03	.240E-03	.536E-03	.900E-03	.134E-02	.184E-02	.539E-02	.104E-01	.164E-01	.306E-01	.466E-01	.635E-01

Table S.13.48

$R = R(D_n, D_l)$ for $K_n = 0.4$ and $K_l = 2.5$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.157E-02	.453E-02	.132E-01	.240E-01	.359E-01	.485E-01	.112E+00	.171E+00	.223E+00	.311E+00	.381E+00	.439E+00
75	.877E-03	.242E-02	.709E-02	.132E-01	.203E-01	.279E-01	.698E-01	.112E+00	.152E+00	.223E+00	.284E+00	.336E+00
100	.595E-03	.157E-02	.453E-02	.850E-02	.132E-01	.184E-01	.484E-01	.804E-01	.112E+00	.171E+00	.223E+00	.269E+00
125	.446E-03	.114E-02	.321E-02	.602E-02	.939E-02	.132E-01	.359E-01	.612E-01	.868E-01	.136E+00	.181E+00	.223E+00
150	.356E-03	.880E-03	.242E-02	.453E-02	.709E-02	.100E-01	.279E-01	.484E-01	.697E-01	.112E+00	.152E+00	.189E+00
175	.295E-03	.713E-03	.192E-02	.357E-02	.558E-02	.789E-02	.224E-01	.394E-01	.575E-01	.940E-01	.129E+00	.163E+00
200	.252E-03	.597E-03	.158E-02	.290E-02	.453E-02	.641E-02	.184E-01	.329E-01	.484E-01	.804E-01	.112E+00	.142E+00
225	.220E-03	.512E-03	.133E-02	.243E-02	.378E-02	.534E-02	.155E-01	.279E-01	.414E-01	.698E-01	.981E-01	.125E+00
250	.195E-03	.448E-03	.114E-02	.207E-02	.321E-02	.453E-02	.132E-01	.240E-01	.359E-01	.612E-01	.868E-01	.112E+00
300	.159E-03	.357E-03	.881E-03	.158E-02	.243E-02	.342E-02	.100E-01	.184E-01	.279E-01	.484E-01	.698E-01	.911E-01
350	.134E-03	.296E-03	.714E-03	.126E-02	.192E-02	.270E-02	.789E-02	.146E-01	.224E-01	.395E-01	.576E-01	.759E-01
400	.116E-03	.253E-03	.598E-03	.104E-02	.158E-02	.220E-02	.642E-02	.120E-01	.184E-01	.329E-01	.485E-01	.644E-01

Table S.13.49

***R* = *R* (D_n, D_l) for K_n = 0.5 and K_l = 0.1 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.223E-02	.466E-02	.101E-01	.165E-01	.239E-01	.322E-01	.931E-01	.191E+00	.324E+00	.629E+00	.855E+00	.950E+00
75	.147E-02	.303E-02	.640E-02	.101E-01	.144E-01	.188E-01	.488E-01	.931E-01	.154E+00	.324E+00	.532E+00	.718E+00
100	.109E-02	.224E-02	.467E-02	.730E-02	.102E-01	.132E-01	.322E-01	.584E-01	.931E-01	.191E+00	.326E+00	.477E+00
125	.871E-03	.178E-02	.368E-02	.570E-02	.790E-02	.102E-01	.238E-01	.417E-01	.646E-01	.128E+00	.216E+00	.323E+00
150	.724E-03	.147E-02	.303E-02	.468E-02	.644E-02	.824E-02	.188E-01	.322E-01	.488E-01	.931E-01	.155E+00	.231E+00
175	.619E-03	.126E-02	.258E-02	.396E-02	.544E-02	.693E-02	.155E-01	.261E-01	.389E-01	.722E-01	.118E+00	.174E+00
200	.541E-03	.110E-02	.224E-02	.344E-02	.470E-02	.598E-02	.132E-01	.219E-01	.322E-01	.584E-01	.937E-01	.137E+00
225	.480E-03	.973E-03	.199E-02	.304E-02	.414E-02	.525E-02	.115E-01	.188E-01	.274E-01	.488E-01	.770E-01	.111E+00
250	.432E-03	.874E-03	.178E-02	.272E-02	.370E-02	.469E-02	.102E-01	.165E-01	.238E-01	.417E-01	.650E-01	.931E-01
300	.359E-03	.726E-03	.148E-02	.225E-02	.305E-02	.385E-02	.823E-02	.132E-01	.188E-01	.322E-01	.491E-01	.690E-01
350	.308E-03	.621E-03	.126E-02	.191E-02	.260E-02	.327E-02	.692E-02	.110E-01	.155E-01	.261E-01	.391E-01	.542E-01
400	.269E-03	.543E-03	.110E-02	.167E-02	.226E-02	.284E-02	.597E-02	.942E-02	.132E-01	.219E-01	.324E-01	.443E-01

Table S.13.50

$R = R(D_n, D_l)$ for $K_n = 0.5$ and $K_l = 0.2$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.223E-02	.467E-02	.102E-01	.166E-01	.242E-01	.326E-01	.953E-01	.195E+00	.328E+00	.616E+00	.827E+00	.925E+00
75	.147E-02	.303E-02	.642E-02	.102E-01	.144E-01	.190E-01	.496E-01	.953E-01	.158E+00	.328E+00	.527E+00	.698E+00
100	.109E-02	.224E-02	.469E-02	.734E-02	.103E-01	.133E-01	.326E-01	.595E-01	.953E-01	.196E+00	.330E+00	.475E+00
125	.871E-03	.178E-02	.369E-02	.573E-02	.793E-02	.102E-01	.241E-01	.424E-01	.660E-01	.131E+00	.221E+00	.328E+00
150	.723E-03	.147E-02	.304E-02	.469E-02	.646E-02	.827E-02	.190E-01	.326E-01	.496E-01	.954E-01	.159E+00	.237E+00
175	.619E-03	.126E-02	.258E-02	.397E-02	.545E-02	.695E-02	.157E-01	.264E-01	.395E-01	.738E-01	.121E+00	.179E+00
200	.541E-03	.110E-02	.225E-02	.345E-02	.471E-02	.599E-02	.133E-01	.221E-01	.326E-01	.596E-01	.958E-01	.141E+00
225	.480E-03	.973E-03	.199E-02	.304E-02	.415E-02	.526E-02	.116E-01	.190E-01	.277E-01	.497E-01	.787E-01	.114E+00
250	.432E-03	.874E-03	.178E-02	.272E-02	.371E-02	.469E-02	.102E-01	.166E-01	.241E-01	.425E-01	.663E-01	.953E-01
300	.359E-03	.727E-03	.148E-02	.225E-02	.306E-02	.386E-02	.827E-02	.133E-01	.190E-01	.327E-01	.499E-01	.704E-01
350	.308E-03	.622E-03	.126E-02	.192E-02	.260E-02	.327E-02	.695E-02	.111E-01	.157E-01	.264E-01	.397E-01	.552E-01
400	.269E-03	.543E-03	.110E-02	.167E-02	.226E-02	.284E-02	.599E-02	.947E-02	.133E-01	.221E-01	.328E-01	.451E-01

Table S.13.51

***R* = *R* (D_n, D_l) for K_n = 0.5 and K_l = 0.3 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.224E-02	.469E-02	.103E-01	.169E-01	.245E-01	.334E-01	.989E-01	.202E+00	.332E+00	.598E+00	.788E+00	.891E+00
75	.147E-02	.304E-02	.646E-02	.103E-01	.146E-01	.193E-01	.511E-01	.990E-01	.164E+00	.333E+00	.515E+00	.670E+00
100	.109E-02	.225E-02	.471E-02	.739E-02	.103E-01	.134E-01	.334E-01	.615E-01	.990E-01	.202E+00	.333E+00	.470E+00
125	.871E-03	.178E-02	.370E-02	.576E-02	.796E-02	.103E-01	.245E-01	.436E-01	.682E-01	.136E+00	.227E+00	.332E+00
150	.724E-03	.148E-02	.305E-02	.472E-02	.648E-02	.833E-02	.193E-01	.334E-01	.511E-01	.992E-01	.164E+00	.243E+00
175	.619E-03	.126E-02	.259E-02	.399E-02	.546E-02	.699E-02	.158E-01	.269E-01	.405E-01	.765E-01	.125E+00	.185E+00
200	.541E-03	.110E-02	.225E-02	.346E-02	.472E-02	.602E-02	.134E-01	.225E-01	.334E-01	.616E-01	.992E-01	.146E+00
225	.480E-03	.974E-03	.199E-02	.305E-02	.416E-02	.529E-02	.117E-01	.193E-01	.283E-01	.512E-01	.813E-01	.119E+00
250	.432E-03	.875E-03	.179E-02	.273E-02	.371E-02	.471E-02	.103E-01	.169E-01	.245E-01	.436E-01	.683E-01	.990E-01
300	.359E-03	.727E-03	.148E-02	.226E-02	.306E-02	.387E-02	.833E-02	.134E-01	.193E-01	.334E-01	.512E-01	.729E-01
350	.308E-03	.622E-03	.126E-02	.192E-02	.260E-02	.328E-02	.699E-02	.112E-01	.159E-01	.270E-01	.406E-01	.569E-01
400	.269E-03	.543E-03	.110E-02	.167E-02	.226E-02	.285E-02	.602E-02	.954E-02	.134E-01	.225E-01	.334E-01	.463E-01

Table S.13.52

***R* = *R* (D_n, D_l) for K_n = 0.5 and K_l = 0.4 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.224E-02	.472E-02	.104E-01	.172E-01	.252E-01	.344E-01	.104E+00	.209E+00	.334E+00	.575E+00	.748E+00	.852E+00
75	.147E-02	.305E-02	.651E-02	.104E-01	.148E-01	.197E-01	.532E-01	.104E+00	.171E+00	.335E+00	.501E+00	.641E+00
100	.110E-02	.225E-02	.474E-02	.746E-02	.104E-01	.137E-01	.344E-01	.642E-01	.104E+00	.209E+00	.334E+00	.460E+00
125	.872E-03	.178E-02	.372E-02	.580E-02	.803E-02	.104E-01	.251E-01	.452E-01	.714E-01	.142E+00	.233E+00	.334E+00
150	.724E-03	.148E-02	.306E-02	.474E-02	.653E-02	.841E-02	.197E-01	.344E-01	.532E-01	.104E+00	.171E+00	.249E+00
175	.620E-03	.126E-02	.260E-02	.401E-02	.550E-02	.705E-02	.161E-01	.277E-01	.420E-01	.801E-01	.131E+00	.192E+00
200	.541E-03	.110E-02	.226E-02	.348E-02	.474E-02	.607E-02	.137E-01	.230E-01	.345E-01	.643E-01	.104E+00	.152E+00
225	.480E-03	.975E-03	.200E-02	.307E-02	.417E-02	.532E-02	.118E-01	.197E-01	.291E-01	.533E-01	.850E-01	.124E+00
250	.432E-03	.876E-03	.179E-02	.274E-02	.372E-02	.474E-02	.104E-01	.172E-01	.252E-01	.453E-01	.714E-01	.104E+00
300	.359E-03	.727E-03	.148E-02	.226E-02	.307E-02	.389E-02	.841E-02	.137E-01	.197E-01	.345E-01	.533E-01	.763E-01
350	.308E-03	.622E-03	.127E-02	.193E-02	.260E-02	.330E-02	.705E-02	.113E-01	.162E-01	.277E-01	.420E-01	.594E-01
400	.269E-03	.543E-03	.110E-02	.168E-02	.226E-02	.286E-02	.607E-02	.966E-02	.137E-01	.231E-01	.345E-01	.481E-01

Table S.13.53

$R = R\ (D_n, D_l)$ for $K_n = 0.5$ and $K_l = 0.5$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.225E-02	.476E-02	.106E-01	.176E-01	.260E-01	.359E-01	.109E+00	.214E+00	.333E+00	.552E+00	.710E+00	.813E+00
75	.148E-02	.307E-02	.658E-02	.106E-01	.151E-01	.202E-01	.559E-01	.109E+00	.177E+00	.333E+00	.484E+00	.611E+00
100	.110E-02	.226E-02	.477E-02	.754E-02	.106E-01	.139E-01	.359E-01	.676E-01	.109E+00	.214E+00	.333E+00	.448E+00
125	.873E-03	.179E-02	.374E-02	.585E-02	.813E-02	.106E-01	.260E-01	.473E-01	.752E-01	.148E+00	.238E+00	.333E+00
150	.725E-03	.148E-02	.308E-02	.478E-02	.659E-02	.853E-02	.202E-01	.359E-01	.559E-01	.109E+00	.177E+00	.253E+00
175	.620E-03	.126E-02	.261E-02	.404E-02	.554E-02	.713E-02	.165E-01	.287E-01	.439E-01	.843E-01	.137E+00	.198E+00
200	.542E-03	.110E-02	.227E-02	.349E-02	.478E-02	.613E-02	.139E-01	.238E-01	.359E-01	.676E-01	.109E+00	.159E+00
225	.481E-03	.977E-03	.200E-02	.308E-02	.420E-02	.537E-02	.120E-01	.203E-01	.302E-01	.559E-01	.895E-01	.130E+00
250	.432E-03	.877E-03	.180E-02	.275E-02	.375E-02	.478E-02	.106E-01	.176E-01	.260E-01	.474E-01	.751E-01	.109E+00
300	.360E-03	.728E-03	.149E-02	.227E-02	.308E-02	.391E-02	.852E-02	.139E-01	.203E-01	.359E-01	.559E-01	.803E-01
350	.308E-03	.623E-03	.127E-02	.193E-02	.261E-02	.331E-02	.713E-02	.115E-01	.165E-01	.287E-01	.439E-01	.624E-01
400	.269E-03	.544E-03	.111E-02	.168E-02	.227E-02	.287E-02	.613E-02	.980E-02	.140E-01	.238E-01	.359E-01	.505E-01

Table S.13.54

***R* = *R* (D_n, D_l) for K_n = 0.5 and K_l = 0.75 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.228E-02	.489E-02	.112E-01	.192E-01	.290E-01	.406E-01	.121E+00	.220E+00	.321E+00	.497E+00	.629E+00	.723E+00
75	.149E-02	.312E-02	.684E-02	.112E-01	.163E-01	.223E-01	.636E-01	.121E+00	.186E+00	.321E+00	.443E+00	.546E+00
100	.110E-02	.229E-02	.491E-02	.787E-02	.112E-01	.150E-01	.406E-01	.767E-01	.121E+00	.220E+00	.321E+00	.414E+00
125	.878E-03	.181E-02	.382E-02	.605E-02	.851E-02	.112E-01	.290E-01	.539E-01	.849E-01	.159E+00	.241E+00	.321E+00
150	.728E-03	.150E-02	.313E-02	.491E-02	.685E-02	.895E-02	.223E-01	.406E-01	.636E-01	.121E+00	.186E+00	.254E+00
175	.622E-03	.127E-02	.265E-02	.413E-02	.572E-02	.743E-02	.180E-01	.321E-01	.499E-01	.947E-01	.148E+00	.205E+00
200	.543E-03	.111E-02	.230E-02	.356E-02	.491E-02	.635E-02	.150E-01	.264E-01	.406E-01	.767E-01	.121E+00	.169E+00
225	.482E-03	.983E-03	.203E-02	.313E-02	.430E-02	.554E-02	.129E-01	.223E-01	.339E-01	.636E-01	.100E+00	.142E+00
250	.433E-03	.882E-03	.182E-02	.280E-02	.383E-02	.491E-02	.112E-01	.192E-01	.290E-01	.539E-01	.849E-01	.121E+00
300	.360E-03	.732E-03	.150E-02	.230E-02	.313E-02	.400E-02	.895E-02	.150E-01	.223E-01	.406E-01	.636E-01	.906E-01
350	.308E-03	.625E-03	.128E-02	.195E-02	.265E-02	.338E-02	.743E-02	.123E-01	.180E-01	.321E-01	.499E-01	.709E-01
400	.269E-03	.546E-03	.111E-02	.170E-02	.230E-02	.292E-02	.635E-02	.104E-01	.150E-01	.264E-01	.406E-01	.574E-01

Table S.13.55

$R = R\ (D_n, D_l)$ for $K_n = 0.5$ and $K_l = 1$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.233E-02	.510E-02	.122E-01	.214E-01	.326E-01	.455E-01	.127E+00	.218E+00	.305E+00	.453E+00	.565E+00	.651E+00
75	.151E-02	.321E-02	.723E-02	.122E-01	.181E-01	.249E-01	.703E-01	.127E+00	.187E+00	.305E+00	.407E+00	.493E+00
100	.112E-02	.234E-02	.511E-02	.838E-02	.122E-01	.165E-01	.455E-01	.837E-01	.127E+00	.218E+00	.304E+00	.383E+00
125	.884E-03	.184E-02	.395E-02	.636E-02	.910E-02	.122E-01	.326E-01	.600E-01	.921E-01	.163E+00	.235E+00	.304E+00
150	.733E-03	.151E-02	.322E-02	.512E-02	.724E-02	.959E-02	.249E-01	.455E-01	.703E-01	.127E+00	.187E+00	.247E+00
175	.626E-03	.129E-02	.271E-02	.428E-02	.600E-02	.789E-02	.199E-01	.361E-01	.557E-01	.102E+00	.153E+00	.205E+00
200	.546E-03	.112E-02	.234E-02	.367E-02	.512E-02	.669E-02	.165E-01	.296E-01	.455E-01	.837E-01	.127E+00	.172E+00
225	.484E-03	.991E-03	.206E-02	.322E-02	.446E-02	.580E-02	.140E-01	.249E-01	.381E-01	.702E-01	.107E+00	.147E+00
250	.435E-03	.889E-03	.184E-02	.286E-02	.395E-02	.512E-02	.122E-01	.214E-01	.326E-01	.600E-01	.921E-01	.127E+00
300	.361E-03	.736E-03	.152E-02	.234E-02	.322E-02	.414E-02	.960E-02	.165E-01	.249E-01	.455E-01	.703E-01	.977E-01
350	.309E-03	.629E-03	.129E-02	.199E-02	.271E-02	.348E-02	.789E-02	.134E-01	.199E-01	.361E-01	.557E-01	.779E-01
400	.270E-03	.549E-03	.112E-02	.172E-02	.235E-02	.300E-02	.669E-02	.112E-01	.165E-01	.296E-01	.455E-01	.638E-01

Table S.13.56

$R = R(D_n, D_l)$ for $K_n = 0.5$ and $K_l = 1.25$ (doses in rad)

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.239E-02	.539E-02	.133E-01	.236E-01	.358E-01	.495E-01	.129E+00	.211E+00	.288E+00	.417E+00	.516E+00	.594E+00
75	.153E-02	.333E-02	.775E-02	.133E-01	.199E-01	.275E-01	.746E-01	.129E+00	.184E+00	.288E+00	.377E+00	.453E+00
100	.113E-02	.240E-02	.540E-02	.904E-02	.133E-01	.182E-01	.495E-01	.879E-01	.129E+00	.211E+00	.288E+00	.356E+00
125	.893E-03	.188E-02	.413E-02	.678E-02	.985E-02	.133E-01	.358E-01	.643E-01	.960E-01	.162E+00	.227E+00	.288E+00
150	.739E-03	.154E-02	.333E-02	.540E-02	.776E-02	.104E-01	.275E-01	.495E-01	.746E-01	.129E+00	.184E+00	.238E+00
175	.630E-03	.131E-02	.280E-02	.448E-02	.638E-02	.848E-02	.220E-01	.396E-01	.600E-01	.105E+00	.153E+00	.200E+00
200	.549E-03	.113E-02	.241E-02	.383E-02	.540E-02	.714E-02	.182E-01	.326E-01	.495E-01	.879E-01	.129E+00	.171E+00
225	.487E-03	.100E-02	.211E-02	.334E-02	.468E-02	.616E-02	.154E-01	.275E-01	.417E-01	.746E-01	.111E+00	.147E+00
250	.437E-03	.897E-03	.188E-02	.296E-02	.413E-02	.540E-02	.133E-01	.236E-01	.358E-01	.643E-01	.960E-01	.129E+00
300	.363E-03	.742E-03	.154E-02	.241E-02	.334E-02	.434E-02	.104E-01	.182E-01	.275E-01	.495E-01	.746E-01	.101E+00
350	.310E-03	.633E-03	.131E-02	.203E-02	.280E-02	.362E-02	.849E-02	.147E-01	.220E-01	.396E-01	.600E-01	.821E-01
400	.271E-03	.552E-03	.114E-02	.176E-02	.241E-02	.310E-02	.715E-02	.122E-01	.182E-01	.326E-01	.495E-01	.681E-01

Table S.13.57

***R* = *R* (D_n, D_l) for K_n = 0.5 and K_l = 1.5 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.247E-02	.573E-02	.144E-01	.255E-01	.383E-01	.522E-01	.129E+00	.204E+00	.273E+00	.388E+00	.478E+00	.549E+00
75	.157E-02	.348E-02	.833E-02	.145E-01	.216E-01	.296E-01	.771E-01	.129E+00	.180E+00	.273E+00	.352E+00	.420E+00
100	.115E-02	.248E-02	.574E-02	.975E-02	.145E-01	.197E-01	.522E-01	.898E-01	.129E+00	.204E+00	.273E+00	.333E+00
125	.904E-03	.193E-02	.434E-02	.726E-02	.106E-01	.145E-01	.383E-01	.669E-01	.976E-01	.159E+00	.218E+00	.272E+00
150	.747E-03	.158E-02	.348E-02	.574E-02	.834E-02	.113E-01	.296E-01	.522E-01	.770E-01	.129E+00	.180E+00	.228E+00
175	.636E-03	.133E-02	.290E-02	.473E-02	.681E-02	.914E-02	.238E-01	.422E-01	.627E-01	.106E+00	.151E+00	.194E+00
200	.553E-03	.115E-02	.249E-02	.402E-02	.574E-02	.766E-02	.197E-01	.350E-01	.522E-01	.898E-01	.129E+00	.167E+00
225	.490E-03	.102E-02	.218E-02	.349E-02	.495E-02	.657E-02	.167E-01	.296E-01	.444E-01	.770E-01	.111E+00	.146E+00
250	.440E-03	.909E-03	.193E-02	.308E-02	.435E-02	.574E-02	.145E-01	.255E-01	.383E-01	.669E-01	.976E-01	.129E+00
300	.365E-03	.750E-03	.158E-02	.249E-02	.349E-02	.457E-02	.113E-01	.198E-01	.296E-01	.522E-01	.770E-01	.103E+00
350	.312E-03	.639E-03	.133E-02	.209E-02	.291E-02	.379E-02	.914E-02	.159E-01	.238E-01	.422E-01	.627E-01	.843E-01
400	.272E-03	.556E-03	.116E-02	.180E-02	.249E-02	.323E-02	.766E-02	.132E-01	.198E-01	.350E-01	.523E-01	.707E-01

Table S.13.58

***R* = *R* (D_n, D_l) for K_n = 0.5 and K_l = 1.75 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.257E-02	.608E-02	.155E-01	.271E-01	.401E-01	.540E-01	.127E+00	.197E+00	.260E+00	.364E+00	.447E+00	.513E+00
75	.161E-02	.365E-02	.891E-02	.155E-01	.230E-01	.313E-01	.782E-01	.127E+00	.174E+00	.260E+00	.332E+00	.394E+00
100	.117E-02	.258E-02	.609E-02	.104E-01	.155E-01	.211E-01	.540E-01	.904E-01	.127E+00	.197E+00	.259E+00	.315E+00
125	.919E-03	.199E-02	.458E-02	.774E-02	.114E-01	.155E-01	.401E-01	.684E-01	.978E-01	.156E+00	.210E+00	.259E+00
150	.756E-03	.162E-02	.365E-02	.610E-02	.891E-02	.121E-01	.313E-01	.540E-01	.781E-01	.127E+00	.174E+00	.218E+00
175	.642E-03	.136E-02	.303E-02	.500E-02	.726E-02	.978E-02	.253E-01	.440E-01	.642E-01	.106E+00	.148E+00	.187E+00
200	.559E-03	.118E-02	.258E-02	.423E-02	.610E-02	.818E-02	.211E-01	.367E-01	.540E-01	.904E-01	.127E+00	.163E+00
225	.494E-03	.103E-02	.225E-02	.366E-02	.524E-02	.700E-02	.179E-01	.313E-01	.462E-01	.781E-01	.111E+00	.143E+00
250	.443E-03	.923E-03	.199E-02	.322E-02	.459E-02	.610E-02	.155E-01	.271E-01	.401E-01	.684E-01	.978E-01	.127E+00
300	.367E-03	.760E-03	.162E-02	.259E-02	.366E-02	.483E-02	.121E-01	.211E-01	.313E-01	.540E-01	.781E-01	.103E+00
350	.313E-03	.646E-03	.136E-02	.216E-02	.303E-02	.398E-02	.978E-02	.170E-01	.253E-01	.440E-01	.643E-01	.852E-01
400	.273E-03	.561E-03	.118E-02	.185E-02	.259E-02	.338E-02	.818E-02	.142E-01	.211E-01	.368E-01	.540E-01	.721E-01

Table S.13.59

***R* = *R* (D_n, D_l) for K_n = 0.5 and K_l = 2 (doses in rad)**

D_n	D_l											
	1	2 4		6	8	10	20	30	40	60	80	100
50	.267E-02	.644E-02	.163E-01	.283E-01	.413E-01	.550E-01	.125E+00	.190E+00	.248E+00	.345E+00	.421E+00	.483E+00
75	.166E-02	.383E-02	.944E-02	.163E-01	.241E-01	.325E-01	.785E-01	.125E+00	.169E+00	.248E+00	.315E+00	.372E+00
100	.120E-02	.269E-02	.645E-02	.111E-01	.163E-01	.221E-01	.550E-01	.902E-01	.125E+00	.190E+00	.248E+00	.299E+00
125	.936E-03	.206E-02	.483E-02	.821E-02	.121E-01	.163E-01	.413E-01	.690E-01	.972E-01	.152E+00	.202E+00	.248E+00
150	.768E-03	.167E-02	.383E-02	.645E-02	.945E-02	.128E-01	.325E-01	.550E-01	.784E-01	.125E+00	.169E+00	.210E+00
175	.651E-03	.140E-02	.317E-02	.528E-02	.769E-02	.104E-01	.265E-01	.452E-01	.650E-01	.105E+00	.144E+00	.181E+00
200	.565E-03	.120E-02	.269E-02	.445E-02	.645E-02	.867E-02	.221E-01	.380E-01	.550E-01	.902E-01	.125E+00	.158E+00
225	.499E-03	.106E-02	.234E-02	.384E-02	.553E-02	.741E-02	.189E-01	.325E-01	.474E-01	.784E-01	.110E+00	.140E+00
250	.447E-03	.940E-03	.206E-02	.336E-02	.483E-02	.645E-02	.163E-01	.283E-01	.413E-01	.690E-01	.972E-01	.125E+00
300	.370E-03	.771E-03	.167E-02	.269E-02	.384E-02	.509E-02	.128E-01	.221E-01	.325E-01	.550E-01	.785E-01	.102E+00
350	.315E-03	.654E-03	.140E-02	.224E-02	.317E-02	.418E-02	.104E-01	.180E-01	.265E-01	.452E-01	.650E-01	.852E-01
400	.275E-03	.568E-03	.121E-02	.191E-02	.269E-02	.354E-02	.867E-02	.150E-01	.221E-01	.380E-01	.550E-01	.726E-01

Table S.13.60

$R = R\ (D_n, D_l)$ for $K_n = 0.5$ and $K_l = 2.5$ (doses in rad)

D_n	D_l										
	1	**2 4**		**6**	**8**	**10**	**20**	**30**	**40**	**60**	**80**	**100**
50	.289E-02	.706E-02	.176E-01	.298E-01	.426E-01	.558E-01	.120E+00	.178E+00	.229E+00	.314E+00	.382E+00	.438E+00
75	.177E-02	.418E-02	.103E-01	.176E-01	.256E-01	.340E-01	.778E-01	.120E+00	.160E+00	.229E+00	.288E+00	.338E+00
100	.126E-02	.290E-02	.707E-02	.121E-01	.176E-01	.236E-01	.558E-01	.886E-01	.120E+00	.178E+00	.229E+00	.274E+00
125	.976E-03	.221E-02	.529E-02	.899E-02	.132E-01	.176E-01	.426E-01	.690E-01	.950E-01	.144E+00	.189E+00	.229E+00
150	.796E-03	.177E-02	.418E-02	.708E-02	.103E-01	.139E-01	.340E-01	.558E-01	.777E-01	.120E+00	.160E+00	.196E+00
175	.671E-03	.148E-02	.344E-02	.579E-02	.844E-02	.113E-01	.280E-01	.464E-01	.652E-01	.102E+00	.137E+00	.170E+00
200	.580E-03	.126E-02	.291E-02	.487E-02	.708E-02	.949E-02	.236E-01	.394E-01	.558E-01	.886E-01	.120E+00	.150E+00
225	.511E-03	.110E-02	.252E-02	.418E-02	.607E-02	.813E-02	.202E-01	.340E-01	.485E-01	.777E-01	.106E+00	.134E+00
250	.457E-03	.980E-03	.221E-02	.366E-02	.529E-02	.708E-02	.176E-01	.298E-01	.426E-01	.690E-01	.950E-01	.120E+00
300	.376E-03	.799E-03	.178E-02	.291E-02	.419E-02	.558E-02	.139E-01	.236E-01	.340E-01	.558E-01	.778E-01	.993E-01
350	.320E-03	.674E-03	.148E-02	.241E-02	.344E-02	.457E-02	.113E-01	.193E-01	.280E-01	.464E-01	.652E-01	.840E-01
400	.278E-03	.583E-03	.127E-02	.205E-02	.291E-02	.386E-02	.950E-02	.162E-01	.236E-01	.394E-01	.558E-01	.723E-01

14.0: DISCUSSION

It is well known that on Earth only those self-organizing systems exist which are able to maximize the reproduction of their species, thereby providing its safety. The same applies to humankind as the part of nature, who, in contrast to members of other species, consciously strives to provide for the safety of the species according to their understanding of their own benefit and the benefit of their offspring.

In the course of evolution nature found many successful ways of achieving its principal objective: to provide safety at different levels of organization of life. The self-organizing systems created during evolution maintain their safety by a hierarchical principle. But only humans are able to approach consciously the problem of correlating their individual safety and that of their offspring with the safety of society and the human species as such.

One of the most important directions in safeguarding the human species is protection of the natural environment. A civilized society spends more and more of its financial resources to achieve this end. An optimal distribution of the always insufficient funds requires a solid scientific and methodological basis. There is a need for a general theory of safety as a separate scientific discipline. Such a theory should serve as a tool for a quantitative determination of an optimal distribution of financial resources for various kinds of activity in order to produce and maintain safe conditions of development of the human society. So far a commonly accepted system of concepts in the sphere of safety does not even exist, nor does an unambiguous definition of terms, such as "hazard", "safety", "risk", etc., and the relationship between them.

A central point in safety theory is to find a correct criterion of safety. The criterion most commonly used nowadays is life expectancy, defined as a function of the mortality rate distribution over age. This criterion takes into account the conditions of life, including safety, over a prolonged period of time. It is much more difficult to predict the expected conditions of living for subsequent generations and their demographic characteristics. A point of principal importance in safety theory is to find a statistical weight of subsequent generations that can be compared to the current one. In other words, we must be able to quantitatively predict how the current environmental changes will affect the life expectancy of future generations.

The sources of risk are contained in the environment (natural and man-made); they are inherent in any kind of human activity, in the human organism itself, and in the social sphere. They act on humans, animals, plants and buildings. Thus, the structure of the safety problem is many-dimensional. First, there are various sources of risk with their probability distributions according to the size of events. Second, there are various objects-victims with their different sensitivities to a given exposure. Third, there are various methods of preventing harmful events, of their localization, alleviation, or elimination. The problem is made much more complex by the fact that man is at the same time a subject producing hazards, an object exposed to hazards, and a subject counteracting against hazards.

One of the greatest sources of risk is our own goals and strivings, which generally are the driving force of our activity. Our efforts should therefore be constantly directed toward persuading humanity

to restrict itself to harmless goals. The example of the former USSR clearly demonstrates what happens when a state neglects the fundamental principle of restricting one's activity to harmless goals, which follows from the general theory of safety. The struggle for nuclear supremacy at any price not only led to the opposite result but brought about ecological troubles and disasters of various kinds which still haunt and confront present-day Russia. The ecological hazard for the Russian population at the end of the 20th century manifests itself in the following basic forms:

- Deterioration of the general quality of the environment leading to a reduction of life expectancy, increase of morbidity and mortality, and deleterious genetic effects.
- Formation of zones of ecological disaster.
- Increased risk of large-scale technogenic calamities.
- Propagation of radioactive contamination in various media.

In Part I Section 1.0 of this document we presented the main concepts and definition of terms pertaining to the problem of safety, such as "hazard," "safety," and "risk." Sections 2-8 are concerned with a detailed analysis of the risk of death due to diseases (2.0), exposure to natural (3.0) and man-made (4.0) environments, professional (5.0) and non-professional (6.0) activity, and to various social factors (7.0). Section 8.0 of Part I is dedicated to the main integrated indices (life expectancy and loss of ability to work) characterizing the population safety conditions in Russia.

The sections of Part II concentrate on estimations of radiation risk for the Russian population in view of the considerable radioactive contamination of some of Russia's territories. First we describe the radiation risk corresponding to the official Russian dose limits with consideration for the demographic structure of the population (9.0). Then the radiation risk is assessed in some western regions of Russia after the Chernobyl disaster of 1986 (10.0), some regions in the South Urals and Siberia after many years of intensive operation of several giant radiochemical nuclear plants (11.0), and in the Altai Territory after above-ground nuclear testing at the Semipalatinsk Test Site from 1949-1963 (12.0).

Finally, Section 13.0 concludes the document with a discussion of risk using a two-staged approach. First, we determined the distribution of radiation doses among the affected residents. Then we moved from radiation doses to the evaluation of risk of adverse effects. A proposed new approach to risk assessment is described, which is based on consideration of both the distribution of radiation doses and also individual variations in radiosensitivity among the exposed population. It is our considered opinion that it is necessary to account for comparatively small part of the population (10% or higher, possibly up to 20%) that is hypersensitive to radiation. Although at high doses and dose rates this subpopulation affects the general picture of radiation damage to the total population only minimally, at lower radiation exposures they demonstrate health effects that do not appear in the majority of the population. Experimental data accumulated in Russia suggest that moderate and low radiation doses and dose rates have greater effect than are predicted on the basis of extrapolation from high doses. The mathematical approach is described in detail in this section, and calculations are given in the supplementary tables to this section. This proposed approach can be employed in future assessments of real and potential risks of adverse health effects after acute radiation exposure.

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